EXHIBIT D

-DRAFT-

Site-wide Human Health Risk Assessment

Libby Asbestos Superfund Site
Libby, Montana

December 2014

CDM Smith

- DRAFT-

Site-wide Human Health Risk Assessment
Libby Asbestos Superfund Site
Libby, Montana

December 2014

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Libby, Montana

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Acronyms and Abbreviations

%	percent
>	greater than
≥	greater than or equal to
<	less than
µm	micrometers
95UCL	95% upper confidence limit
ABS	activity-based sampling
Ago	area of grid opening
ARP	Lincoln County Asbestos Resource Program
ASTM	American Society for Testing and Materials
ATS	American Thoracic Society
ATSDR	Agency for Toxic Substances and Disease Registry
ATV	all-terrain vehicle
BE	best estimate
BNSF	Burlington Northern and Santa Fe
C	concentration
CB&I	CB&I Federal Services, LLC
cc^{-1}	per cubic centimeter of air
CDM Smith	CDM Federal Programs Corporation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	conceptual site model
CTE	central tendency exposure
CUA	common-use area
DEQ	Montana Department of Environmental Quality
DPT	diffuse pleural thickening
ED	exposure duration
EDS	energy dispersive spectroscopy
EF	exposure frequency
EFA	effective area of the filter
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ESATR8	Environmental Services Assistance Team, EPA Region 8
ET	exposure time
F	f-factor
FBAS	fluidized bed asbestos segregator
f/cc	fibers per cubic centimeter of air
FS	feasibility study
GO	grid opening
GPS	global positioning system
Grace	W.R. Grace Company
H&S	health and safety
HDR	HDR Engineering, Inc.
HEI-AR	Health Effects Institute – Asbestos Research
HEPA	high-efficiency particulate air
HHRA	human health risk assessment

HI	hazard index
HQ	hazard quotient
IARC	International Agency for Research on Cancer
IRIS	Integrated Risk Information System
ISO	International Organization of Standardization
IUR	inhalation unit risk
KBPID	Kootenai Business Park Industrial District
L	liters
LA	Libby amphibole asbestos
LPT	localized pleural thickening
LRC	Lower Rainy Creek
LUA	limited-use area
MCL	maximum contaminant level
MDT	Montana Department of Transportation
mL	milliliters
mm^2	square millimeters
MP	mile post
mph	miles per hour
MotoX	motorcross
Ms/g	million structures per gram
NAS	National Academy of Sciences
ND	non-detect
NIOSH	National Institute of Occupational Safety and Health
NIST	National Institute of Standards and Technology
NPL	National Priorities List
NTP	National Toxicology Program
NVLAP	National Voluntary Laboratory Accreditation Program
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OU	operable unit
PCM	phase contrast microscopy
PCME	phase contrast microscopy-equivalent
PLM	polarized light microscopy
PLM-Grav	polarized light microscopy-gravimetric
PLM-VE	polarized light microscopy using visual area estimation
QA	quality assurance
QC	quality control
RAGS	Risk Assessment Guidance for Superfund
RfC	reference concentration
RI	remedial investigation
RME	reasonable maximum exposure
ROD	record of decision
ROW	right-of-way
s	structures
s/cc	structures per cubic centimeter of air
s/cm^2	structures per square centimeter of area
s/g	structures per gram
SAB	Scientific Advisory Board
SAED	selective area electron diffraction

SAP	sampling and analysis plan
Site	Libby Asbestos Superfund Site
SOP	standard operating procedure
SQAPP	Supplemental Remedial Investigation Quality Assessment and Project Plan
SUA	specific-use area
TEM	transmission electron microscopy
TRW	Technical Review Workgroup
Tetra Tech	Tetra Tech EM Inc.
TWF	time-weighting factor
UB	upper-bound
UF	uncertainty factor
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
V	volume
VI	vermiculite insulation
VV	visible vermiculite
WHO	World Health Organization

EXECUTIVE SUMMARY

Introduction

Libby is a community in northwestern Montana that is located near a former vermiculite mine (**Figure ES-1**). The vermiculite mine near Libby began limited operations in the 1920s and was operated on a larger scale by the W.R. Grace Company (Grace) from approximately 1963 to 1990. Vermiculite from the mine contains varying concentrations of amphibole asbestos, referred to as "Libby amphibole asbestos" or LA. Epidemiological studies revealed that workers at the mine had an increased risk of developing asbestos-related lung disease (McDonald *et al.* 1986a, 1986b, 2004; Amandus and Wheeler 1987; Amandus *et al.* 1987a,b; Whitehouse 2004; Sullivan 2007). Additionally, radiographic abnormalities were observed in 17.8 percent (%) of the general population of Libby, including former workers, family members of workers, and other residents of Libby and Troy, Montana (Peipins *et al.* 2003; Whitehouse *et al.* 2008; Antao *et al.* 2012; Larson *et al.* 2010, 2012a, 2012b).

In October 2002, the Libby Asbestos Superfund Site (Site) was listed on the U.S. Environmental Protection Agency (EPA) National Priorities List (NPL). The Site includes homes and businesses that may have become contaminated with LA as a result of the vermiculite mining and processing conducted in and around Libby, as well as other areas that may have been affected by mining-related releases of LA. In addition to vermiculite mining and processing activities, LA contamination also occurred as a consequence of use of LA-contaminated vermiculite as building insulation in residential and commercial buildings and as soil amendments (e.g., gardens and flowerbeds), use of LA-contaminated building materials (e.g., mortar, chinking), and other uses.

The purpose of this document is to quantify potential human health risks from exposures to LA at the Site under current and future conditions. This risk assessment differs from other "typical" Superfund risk assessments in that extensive interior and exterior removal actions have been conducted at the Site for more than 10 years, prior to the completion of the risk assessment, to allow for the timely removal of LA contamination while awaiting the necessary exposure and toxicity data needed complete a quantitative assessment of human health risk. Results of this risk assessment are intended to help Site managers determine if past removal actions have been sufficient to mitigate risk, if additional remedial actions are necessary to address risks, and if so, which exposure pathways would need to be addressed in future remedial actions.

Exposure Assessment

Conceptual Site Model

Historical mining, milling, and processing operations, use of vermiculite in building materials, transport of mining-related materials, tailings, and waste, and runoff from the mine site are known to have released LA to the environment. People may be exposed to LA by two exposure routes: inhalation and ingestion. Of these two exposure routes, inhalation exposure of LA is considered to be of greatest concern.

Asbestos fibers in source materials are typically not inherently hazardous, unless the asbestos is released from the source material into air where it can be inhaled (EPA 2008a). Asbestos fibers may become airborne in a number of ways. This may include natural forces, such as wind blowing over a contaminated soil, or human activities that disturb contaminated sources, such as soil or indoor dust. **Figure ES-2** presents the conceptual site model (CSM) that depicts how LA in source media can be

transported in the environment to exposure media that humans may encounter at the Site. The two main types of exposure media are indoor air and outdoor air. **Table ES-1** summarizes the inhalation exposure pathways and populations that will be evaluated in the human health risk assessment (HHRA).

Exposure Parameters

The risk assessment evaluates potential inhalation exposures for several exposure populations, including residents, recreational visitors, teachers/students, and several types of workers (indoor workers, local tradespeople, outdoor workers). Exposure estimates in the risk assessment do not seek to evaluate exposures for specific individuals. Rather, risk estimates are calculated for representative members of the exposure population, calculating risks based on both members of the population with "typical" levels of exposure and members of the population with "high-end" exposures. These two exposure estimates are referred to as central tendency exposure (CTE) and reasonable maximum exposure (RME), respectively.

For each exposure scenario evaluated in the risk assessment, information on estimated exposure time (ET, in hours per day), exposure frequency (EF, in days per year), and exposure duration (ED, in years) is used to derive a lifetime time-weighting factor (TWF) as follows:

$$TWF = (ET/24 \cdot EF/365 \cdot ED/70)$$

The value of the TWF ranges from zero to one, and describes the average fraction of a lifetime during which the specific exposure scenario occurs.

Exposure Point Concentrations

Predicting the LA levels in air based on measured LA levels in source media is extremely difficult. For this reason, EPA recommends an empiric approach for investigating asbestos-contaminated Superfund sites, where concentrations of asbestos in air from source disturbances are measured rather than predicted (EPA 2008a). This type of sampling is referred to as activity-based sampling (ABS).

To date, more than two dozen different ABS investigations have been conducted at the Site to evaluate potential exposures to LA from various disturbances of source media. These studies have included a wide range of activities, including, but not limited to, dusting and vacuuming inside residences, raking/mowing/digging in yard soil, riding all-terrain vehicles (ATVs), bicycling and driving on roads, and various worker activities. In total, more than 3,100 ABS air samples have been collected at the Site since 2001. In addition, more than 1,500 outdoor ambient air samples have been collected at the Site.

All ABS and ambient air samples have been analyzed by transmission electron microscopy (TEM). During the analysis, detailed information for each observed asbestos structure (e.g., asbestos type, structure type, length, width) is recorded. For the purposes of computing risk estimates, it is necessary to use the results from the TEM analysis to estimate what would have been detected had the sample been analyzed by phase contrast microscopy (PCM). This is because available toxicity information is based on workplace studies that used PCM as the primary method for analysis. For convenience, structures detected under TEM that meet the recording rules for PCM are referred to as PCM-equivalent (PCME) structures. TEM analysis results for air samples are expressed as PCME LA structures per cubic centimeter of air (s/cc).

In accordance with EPA asbestos risk assessment guidance (EPA 2008a), exposure point concentrations (EPCs) for each exposure scenario are calculated as the sample mean, evaluating non-detect samples at a concentration value of zero. In cases where air filters required the use of indirect preparation techniques prior to TEM analysis, the reported PCME LA air concentration was adjusted (decreased) by a factor of 2.5 (Berry *et al.* 2014) to avoid potentially biasing calculated EPCs high due to the effect of indirect preparation.

Toxicity Assessment

The adverse effects of asbestos exposure in humans have been the subject of a large number of studies and publications. Exposure to asbestos may induce several types of both non-cancer and cancer effects. A detailed summary of the cancer and non-cancer effects of asbestos is provided in the Agency for Toxic Substances and Disease Registry (ATSDR) *Toxicological Profile for Asbestos* (ATSDR 2001) and in EPA's *Airborne Asbestos Health Assessment Update* (EPA 1986). A detailed summary of effects related specifically to LA is provided in the *Toxicological Review for Libby Amphibole Asbestos* (EPA 2014c).

Cancer Effects

Many epidemiological studies have reported increased mortality from cancer in workers exposed to asbestos, especially from lung cancer and mesothelioma (tumor of the thin membrane that covers and protects the internal organs of the body). In addition, a number of studies suggest asbestos exposure may increase risk of cancer at various gastrointestinal sites. Based on these findings, and supported by extensive carcinogenicity data from animal studies, EPA has classified asbestos as a known human carcinogen.

Carcinogenic risk from inhalation exposure is determined based on an inhalation unit risk (IUR) value, which is defined as the excess lifetime cancer risk estimated to result from continuous exposure to one asbestos fiber per cubic centimeter of air (1 f/cc). The LA-specific IUR, referred to as IUR_{LA}, is derived from a cohort of workers employed at the vermiculite mining and milling operation in and around Libby, referred to as the "Libby worker cohort". The IUR_{LA} is 0.17 (PCM f/cc)$^{-1}$ (EPA 2014c).

Non-Cancer Effects

Non-cancer effects from asbestos exposure include asbestosis (formation of scar tissue in the lung parenchyma) and several types of abnormalities in the pleura (the membrane surrounding the lungs), such as pleural effusions (excess fluid accumulation in the pleural space), pleural plaques (collagen deposits and calcification), and pleural thickening.

Non-cancer risks from inhalation exposure are determined based on a reference concentration (RfC) value. Exposures below the RfC are considered to be without risk of adverse non-cancer health effects, while exposures above the RfC may cause an effect, depending on the exposure level. The LA-specific RfC, referred to as RfC_{LA}, is derived from a cohort of workers employed at the O.M. Scott Plant in Marysville, Ohio. This plant utilized vermiculite ore that originated from the vermiculite mine in Libby from 1959 to 1980. Localized pleural thickening was selected as the critical effect endpoint for the derivation of the RfC_{LA}. The RfC_{LA} is 0.00009 PCM f/cc (EPA 2014c).

Risk Characterization

Basic Equations

The basic equation used to estimate excess lifetime cancer risk from inhalation of LA is:

$$Risk = EPC \cdot TWF \cdot IUR_{LA}$$

where:

Risk = Lifetime excess risk of developing cancer (lung cancer or mesothelioma) as a consequence of LA exposure.

EPC = Exposure point concentration of LA in air (PCME LA s/cc). The EPC is an estimate of the long-term average concentration of LA in inhaled air for the specific activity being assessed.

TWF = Time-weighting factor for the specific activity being assessed.

IUR_{LA} = LA-specific inhalation unit risk $(0.17 \text{ PCM s/cc})^{-1}$

The basic equation used for characterizing non-cancer hazards from inhalation exposures to LA is as follows:

$$HQ = EPC \cdot TWF / RfC_{LA}$$

where:

HQ = Hazard quotient for non-cancer effects from LA exposure

EPC = Exposure point concentration of LA in air (PCME LA s/cc)

TWF = Time-weighting factor

RfC_{LA} = LA-specific reference concentration (0.00009 PCM s/cc)

Risk Interpretation

In general, EPA considers cumulative excess cancer risks[1] that are below about 1E-06 to be negligible, and risks above 1E-04 to be sufficiently large that some form of remedial action is desirable. Excess cancer risks that range between 1E-04 and 1E-06 are generally considered to be acceptable, although this is evaluated on a case-by-case basis, and EPA may determine that risks lower than 1E-04 are not sufficiently protective and warrant remedial action.

For non-cancer, if the cumulative HQ (referred to as the hazard index [HI]) is less than or equal to 1, then remedial action is generally not warranted. If the HI exceeds 1, there is some possibility that non-cancer effects may occur, although an HI above 1 does not indicate an effect will definitely occur. However, the larger the HI value, the more likely it is that an adverse effect may occur.

[1] Note that excess cancer risk can be expressed in several formats. A cancer risk expressed in a scientific notation format as 1E-06 is equivalent to 1 in 1,000,000 (one in a million) or 1×10^{-6}. Similarly, a cancer risk of 1E-04 is equivalent to 1 in 10,000 (one in ten thousand) or 1×10^{-4}.

Scenario-Specific Risk Characterization

Risks from Exposures to Ambient Air

In the past (circa 1970s), ambient air concentrations as high as 1.5 PCM f/cc were measured in downtown Libby when the mine was in operation. Beginning in 2006, there have been several long-term outdoor ambient air monitoring studies conducted in Libby, Troy, and at the mine site. These data show that average ambient air concentrations in the Libby community and in Troy are less than 0.00001 PCME LA s/cc under current conditions. Current ambient air concentrations at the Site are greatly improved relative to historical conditions and are consistent with asbestos levels that have been measured in ambient air in Eureka and Helena, Montana, as well as across the country (SRC, Inc. 2013a).

Data from the recent ambient air monitoring studies at the Site were used to calculate EPCs for use in evaluating potential exposures to LA in ambient air. All individuals at the Site have the potential to be exposed to LA in ambient air. However, for simplicity, risk estimates from exposures to ambient air were calculated for each exposure area based on the maximally-exposed receptor (e.g., residential exposure scenario in Libby). RME cancer risks are at or below 1E-06 and non-cancer HQs are below 0.1 for all Site exposure locations; CTE cancer risks and non-cancer HQs are even lower. These results indicate that exposures to LA in ambient air are not likely to be of concern to individuals at the Site and are not likely to contribute significantly to cumulative risks.

Risks from Exposures During Soil/Duff Disturbances

Overview

Potential exposures to LA during disturbances of soil/duff can occur for a wide range of receptor types and exposure scenarios. More than 80 different types of exposures during soil/duff disturbances were evaluated, encompassing multiple disturbance activities, exposure populations, exposure locations, and LA concentrations. In reviewing the risk estimates for exposures during soil/duff disturbance activities, there are a number of general conclusions that can be drawn:

- Estimated cancer risks and non-cancer HQs span more than four orders of magnitude depending upon the exposure scenario.
- For a given exposure scenario, non-cancer HQs can exceed 1 even when cancer risks are less than 1E-04, which indicates that non-cancer exposure is a more sensitive metric of potential concern. (For LA, a non-cancer HQ of 1 is approximately equivalent to a cancer risk of 1E-05.)
- There were only a few soil/duff disturbance exposure scenarios where risks from the exposure pathway alone had the potential to be above a level of concern based on RME, including residential and outdoor worker exposures during disturbances of yard soils with detected LA at properties in Libby and Troy, outdoor worker exposures during disturbances of subsurface soils with LA contamination at properties in Libby and Troy, and recreational visitor exposures during disturbances of soil/duff while hiking along Rainy Creek.
- Quantitative risks were not calculated for potential exposures to trespassers in the mined area or for workers exposed to residual LA in subsurface soils in the former Screening Plant and Export Plant areas; however, these exposure scenarios are presumed to result in potentially significant exposures and risks.

- Exposure to LA in outdoor air during yard soil disturbances has the potential to be an important exposure scenario. Even when only trace levels of LA are present in the soil, this exposure scenario, when considered alone, could yield non-cancer HQs above 1, depending upon the spatial extent of the LA in soil and the frequency and intensity that these soils are disturbed.

Extrapolation to Properties without ABS

As noted above, exposure to LA in outdoor air during yard soil disturbances has the potential to be an important exposure pathway. There are more than 5,000 residential/commercial properties in Libby and Troy. Because it is not feasible to evaluate risks by conducting outdoor ABS at every property, it is necessary to use the measured ABS data from the properties where ABS has been performed to draw risk conclusions about properties where ABS has not been performed. This is accomplished by assuming that properties without ABS data, but having the same LA soil level and similar disturbance activities, will have similar outdoor air concentrations as properties with ABS data.

Table ES-2 presents estimated RME cancer risks and non-cancer HQs from exposures to LA during soil disturbances for a range of LA soil levels at residential properties in Libby and Troy. In interpreting these risk estimates, it is important to understand that these calculations are intended to represent a given LA soil concentration. However, a specified exposure area for a property may have varying LA soil concentrations with differing spatial extents. The evaluation of risk at a property is based on the average exposure across the entire exposure area. Thus, for exposure areas that encompass varying soil concentrations, it is necessary to derive a spatially-weighted average risk estimate for the entire exposure area. **Figure ES-3** presents a simplified example of this approach.

Background LA Concentrations in Soil

EPA has conducted several investigations at the Site to characterize LA in soil from areas that are thought to be representative of "background" conditions, meaning that the soils are not expected to be affected by anthropogenic releases from vermiculite mining and processing activities. LA structures have been consistently detected in background soils within the Kootenai Valley. However, potential exposures and risks from LA in background soil are likely to be low.

Risks from Exposures to Indoor Air

There are a wide range of different activities that could occur inside buildings (residences, businesses, schools, etc.) at the Site that could result in exposures to LA. There have been several indoor ABS investigations to evaluate LA concentrations in air during various indoor disturbance scenarios, including indoor exposures inside residences, schools, and commercial and industrial buildings in Libby and Troy. In general, ABS air samples were collected under two representative conditions – active and passive behaviors. Active behaviors include indoor activities in which a person is moving about the building and potentially disturbing indoor sources; such activities have included walking from room to room, sitting down on upholstered chairs, sweeping, and vacuuming. Passive behaviors are minimally energetic actions, such as sitting and reading a book, watching television, and working at a desk, that will have low tendency to disturb any indoor source materials. In addition, air samples were also collected to evaluate potential exposures to local tradespeople (e.g., carpenter, electrician, plumber) from high intensity disturbances of vermiculite insulation (VI) or other asbestos-containing building materials.

With the exception of indoor exposures at properties under "pre-removal" conditions and during tradesperson activities (discussed below), estimated RME cancer risks were below 1E-04 and non-cancer HQs were below 1 for all indoor exposure scenarios.

Estimated RME non-cancer HQs were greater than 1 for both residential exposures and indoor worker exposures to LA inside "pre-removal" properties (these are properties where an interior removal has been deemed necessary, but a removal had not been completed at the time of the ABS). Activities associated with active disturbance behaviors contributed most to total exposures. Non-cancer HQs were below 1 for properties where an interior removal has been completed ("post-removal") and for properties where an interior removal was deemed not to be necessary ("no removal required"). These results demonstrate that interior investigations and removals have been effective at identifying and mitigating sources of LA inside properties.

Exposures of local tradespeople to LA while working inside buildings have the potential to result in RME cancer risks at or above 1E-04 and non-cancer HQs above 1 for all the activities investigated, which included active disturbances of VI (e.g., wall demolition, attic detailing, cleaning living space areas with visible VI). These results indicate that local tradesperson exposures have the potential to be significant and result in risks above a level of concern if appropriate personal protective measures are not employed to mitigate exposures during active disturbances of indoor source materials. There is the potential for tradesperson exposures to occur, even for properties that have had an interior removal or where no interior removal has been deemed necessary, if source materials have been left in place (e.g., VI contained within walls).

Risks from Exposures during Disturbances of Wood-Related Materials

Extensive data have been collected in the forested area near the mine site (CDM Smith 2013a) and in the forested area near the current Site NPL boundary (CDM Smith 2013g). These data show that LA structures are present on the outer bark surface of trees at the Site. If LA-containing trees or wood-related materials (e.g., woodchips, mulch) are disturbed, people may be exposed to LA that is released to air from the wood. If LA-containing trees are used as a source of firewood (e.g., in a residential woodstove), studies have shown that LA fibers can become concentrated in the resulting ash (Ward *et al.* 2009; EPA 2012c), which itself can become a source of potential LA exposure.

A number of ABS studies have been performed at the Site to provide measured data on LA concentrations in air during a variety of disturbances of wood-related materials, including ABS studies during residential wood harvesting activities, commercial logging activities, wood chipping activities, forest maintenance activities, woodchip/mulch disturbance activities, and woodstove ash disturbance activities. With the exception of activities related to commercial logging and the removal of ash from a woodstove (discussed below), estimated RME cancer risks were below 1E-04 and non-cancer HQs were below 1 for all wood-related exposure scenarios.

When commercial logging activities were conducted in an area located near the mine with higher concentrations of LA in tree bark and duff, estimated RME cancer risks for all commercial logging activities were below 1E-04, but non-cancer HQs were at or above 1 during timber skidding and site restoration activities. However, when commercial logging activities were conducted in an area further from the mine, where concentrations of LA in tree bark and duff were lower, estimated RME cancer risks were below 1E-04 and non-cancer HQs were below 1 for all commercial logging activities.

Estimated RME non-cancer HQs for activities associated with the removal of ash from a woodstove differed depending on the source of the firewood that was burned. The estimated HQ was 1 when firewood was collected from a location near the mine (where tree bark LA levels are highest), but HQs were below 1 when firewood was collected from a location intermediate or far from the mine. RME cancer risks from exposure to LA in woodstove ash were below 1E-04 regardless of the wood source.

These risk estimates demonstrate that exposures to LA in ash may contribute significantly to cumulative exposures, especially if the ash is derived from a wood source in close proximity to the mine.

Cumulative Risk Characterization

Basic Approach

The calculation of cumulative risks is complicated by the fact that the exposure pattern of each individual at the Site may be unique. However, EPA does not typically perform risk calculations for specific individuals, but rather for generic classes of receptor populations with common exposure patterns. Thus, the goal of the cumulative risk assessment is to illustrate how risk depends on different types of disturbance activities, LA levels in the source media, and exposure locations.

Cumulative risk from asbestos is expressed as the sum of all the cancer risks or non-cancer HQs from various types of asbestos exposure pathways. Exposure-specific TWF values for use in the cumulative assessment were selected by specifying the fraction of the lifetime spent engaging in each exposure scenario, taking care to ensure that the cumulative TWF is equal to 1.0. This approach is illustrated in **Figure ES-4**.

Cumulative Risk Examples

There are essentially an infinite number of possible exposure scenario combinations that could be evaluated in the cumulative risk assessment for the Site. The choice of which combinations to evaluate is a matter of judgment. For the purposes of this risk assessment, several alternate cumulative exposure scenario combinations were evaluated, representing a wide range of potential cumulative risks. These examples help to identify which exposure scenarios that tend to have the largest contribution to cumulative risk.

Figure ES-5 presents a graphical illustration of the cumulative assessment for one example receptor scenario. In this figure, the upper panel illustrates the fraction of time that each exposure pathway contributes to the total lifetime (i.e., a 70-year lifetime). The lower panel illustrates the contribution of each exposure pathway to the cumulative HI. The table below the figures provides a tabular presentation of the information shown in the two figures. (Note: This figure only presents cumulative HIs as the non-cancer endpoint appears to be the more sensitive metric of potential risk.)

In reviewing the cumulative exposure scenarios, several general observations can be made:

- Cumulative HI estimates were below 1 when exposures occurred at properties and locations with lower levels of LA. However, cumulative HI estimates were above 1 when exposures occurred at properties and locations with higher levels of LA.

- Exposure pathways that contributed the most time to the total lifetime exposure do not necessarily contribute most to the cumulative HI. In some cases, exposure pathways that contribute little to the total lifetime exposure time can contribute significantly to the cumulative HI. For example, in **Figure ES-5**, exposures to LA in outdoor air during disturbances of yard soil (exposure scenario "D") contributes about 5% to the total lifetime exposure time, but about 25% to the cumulative HI.

- When cumulative exposure includes exposure pathways that actively disturb LA-contaminated source materials (e.g., hiking along lower Rainy Creek near the mine site, disturbing soils with

detected LA, performing timber skidding operations near the mine site, or disturbing VI during tradesperson activities), these pathways are important risk drivers for cumulative HI estimates.

- It is possible to reduce cumulative exposures and risks, without altering activity behavior patterns, by lowering LA levels in source media where disturbance activities are performed (e.g., removing yard soil with LA) (see **Figure ES-6**) and/or by changing the locations where the activities are performed (e.g., collecting firewood or performing logging in areas further from the mine site) (see **Figure ES-7**).

- As illustrated in **Figure ES-8**, it is not necessary to address every single exposure pathway to significantly lower cumulative risk. Addressing exposures for small subset of the potential exposure pathways, focusing on risk drivers, will have the greatest impact in lowering cumulative exposures and risks.

- It is possible for individual exposure pathway HQs to be below 1, but the cumulative HI across all exposure pathways to be above 1. Thus, risk managers should consider both cumulative risks and individual exposure pathway risks to identify potential risk drivers to guide decisions on future remedial levels and/or institutional controls.

Uncertainty Assessment

As with all HHRAs, uncertainties exist due to limitations in the exposure and toxicity assessments and our ability to accurately determine cumulative exposure and risk from multiple sources over a lifetime. This risk assessment has used the best available science to evaluate potential human health exposures and risks from LA at the Site; however, there are number of sources of uncertainty that affect the risk estimates that must be considered when making risk management decisions. The most important of these uncertainties are listed below.

- Uncertainty in true long-term average LA concentrations in air
- Uncertainty in the EPC due to non-detects
- Uncertainty due to air filter preparation methods
- Uncertainty due to analytical methods
- Uncertainty due to field collection methods
- Uncertainty in human exposure patterns
- Uncertainty in toxicity values used in risk characterization
- Uncertainty in the cumulative risk estimates

Because of these uncertainties, the cancer risks and non-cancer HQs for individual exposure scenarios are uncertain, and consequently all estimates of cumulative cancer risks and non-cancer HI values presented in this HHRA are also uncertain, and should be considered to be approximate. Actual risks may be either higher or lower than estimated.

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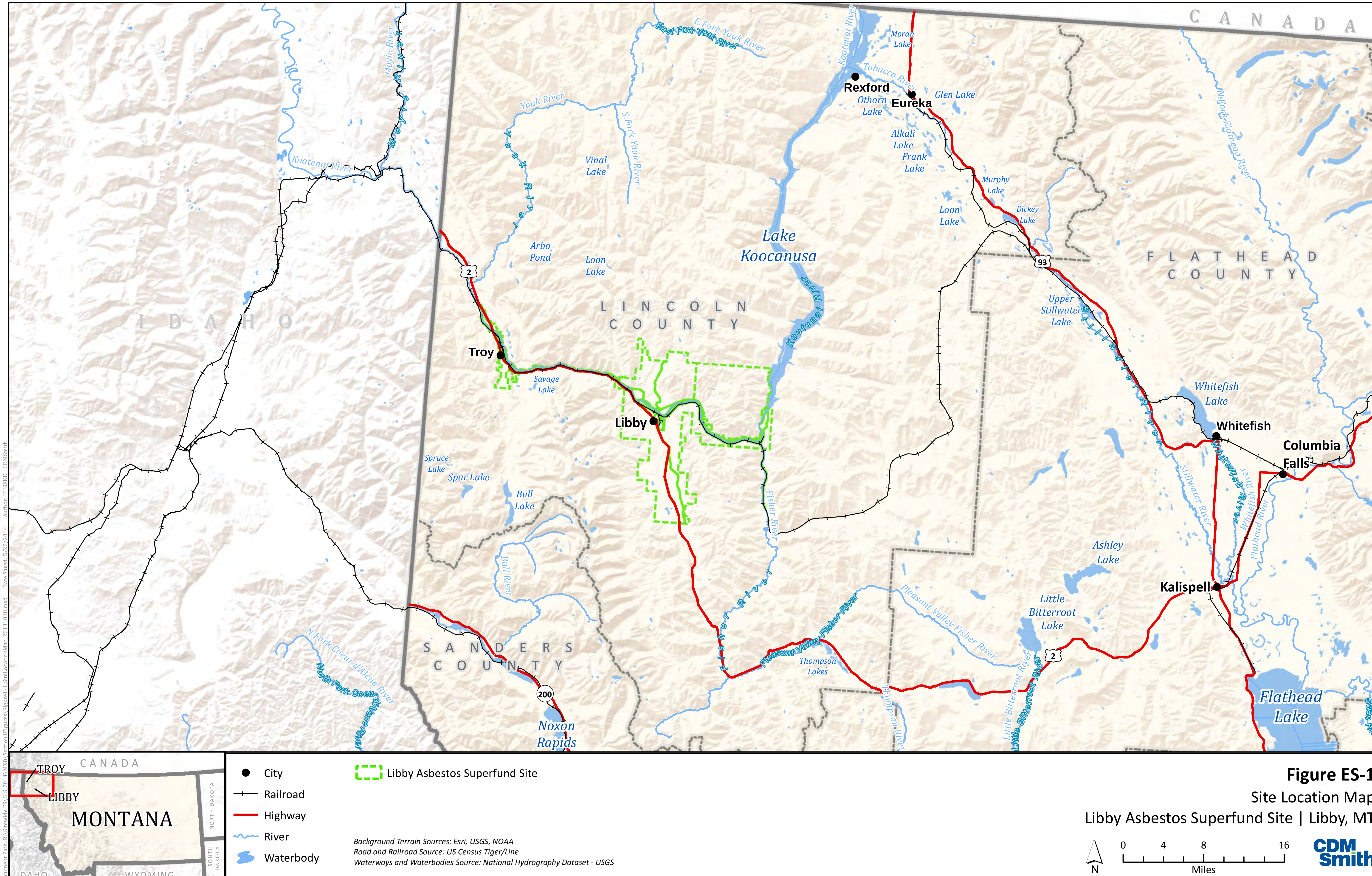


Figure ES-1

Site Location Map

Libby Asbestos Superfund Site | Libby, MT

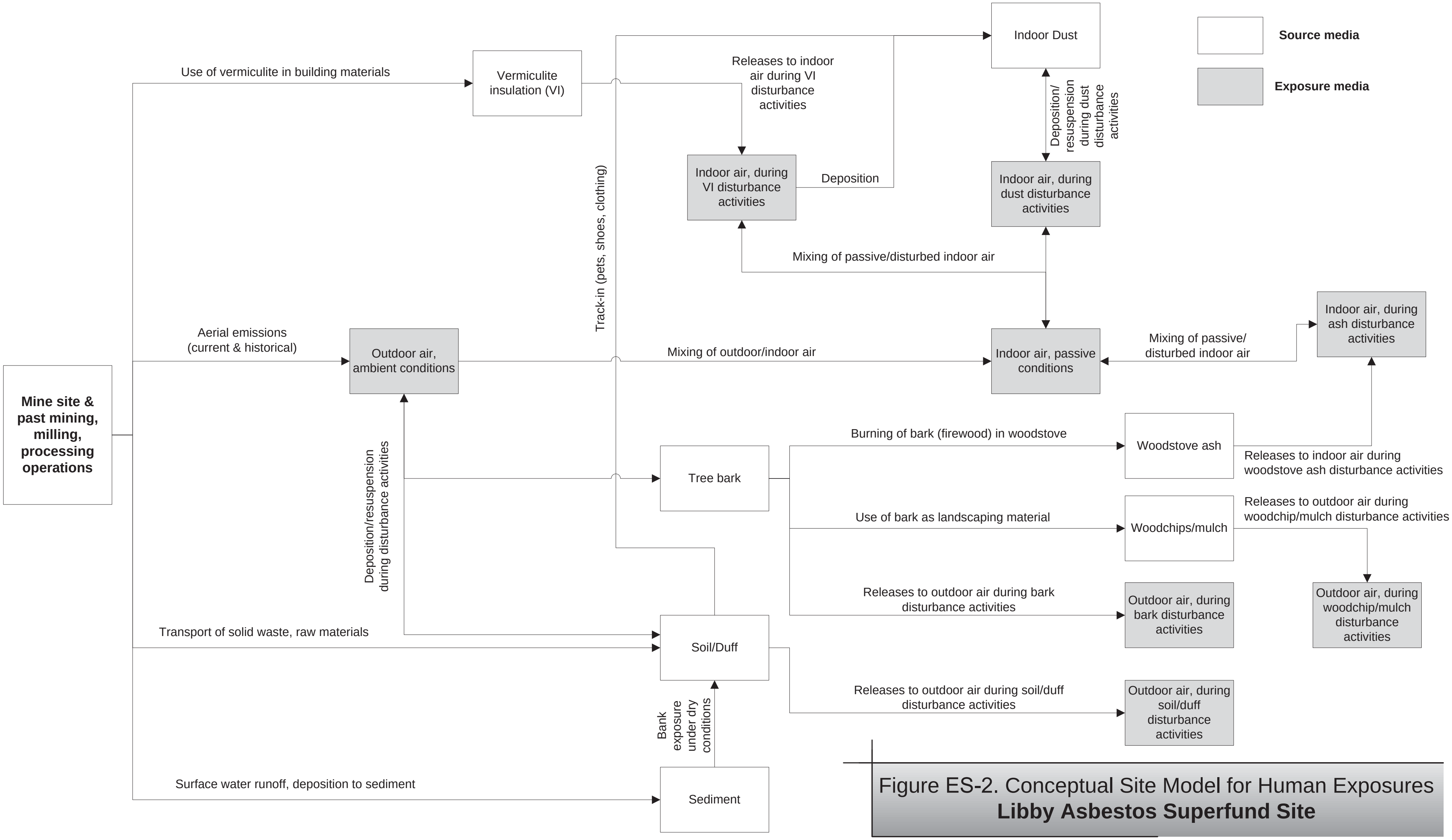


Figure ES-2. Conceptual Site Model for Human Exposures
Libby Asbestos Superfund Site

FIGURE ES-3
Example of Exposure Area Spatial-Weighting Approach

Panel A: Exposure Area Soil Concentrations

Soil Sample #1:
Non-detect

Soil Sample #2:
Trace (<0.2%)

Soil Sample #3:
1%

Panel B: Estimated HQs* for Each Area

Non-detect
Soil Concentration HQ = 0.1

Trace (<0.2%)
Soil Concentration HQ = 2

1%
Soil Concentration HQ = 6

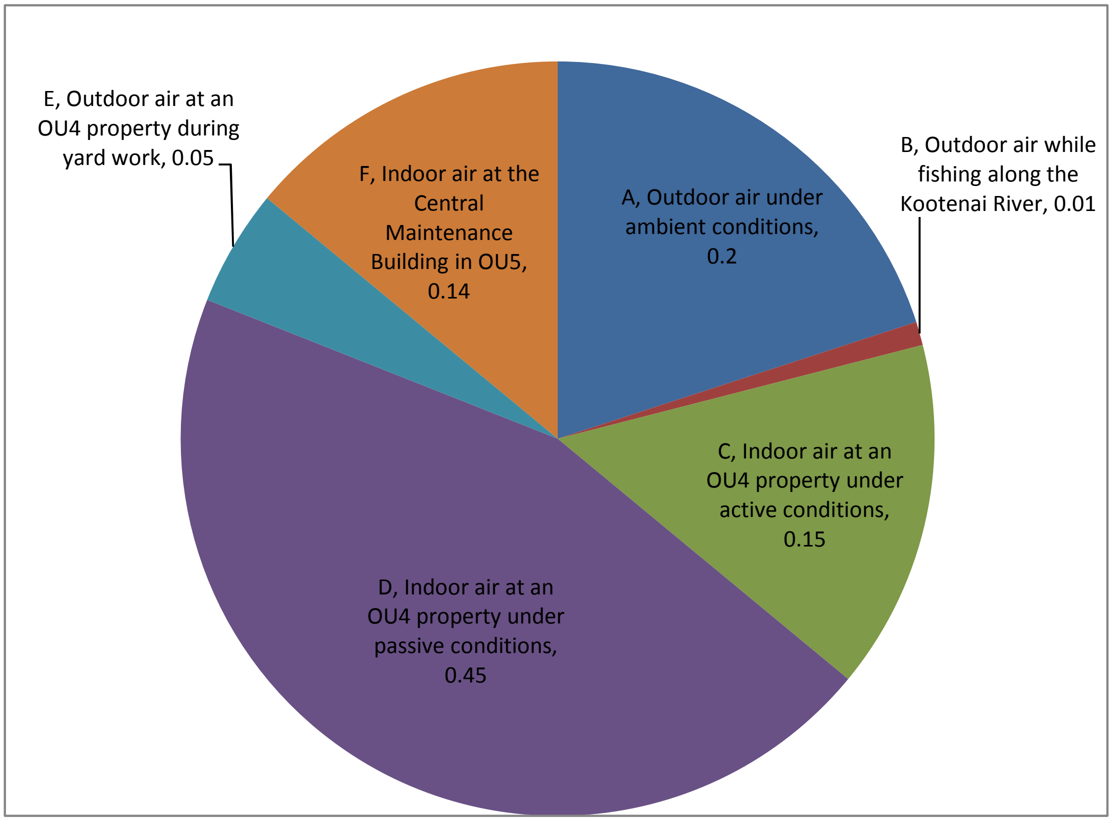
Panel C: Estimated Average HQ for the Entire Exposure Area

Exposure Area HQ =
$(0.1 \cdot 0.5) +$
$(2 \cdot 0.25) +$
$(6 \cdot 0.25)$
= **2**

*Based on Libby Yard Soil Disturbance Residential HQs (see **Table ES-2**)

HQ = Hazard Quotient

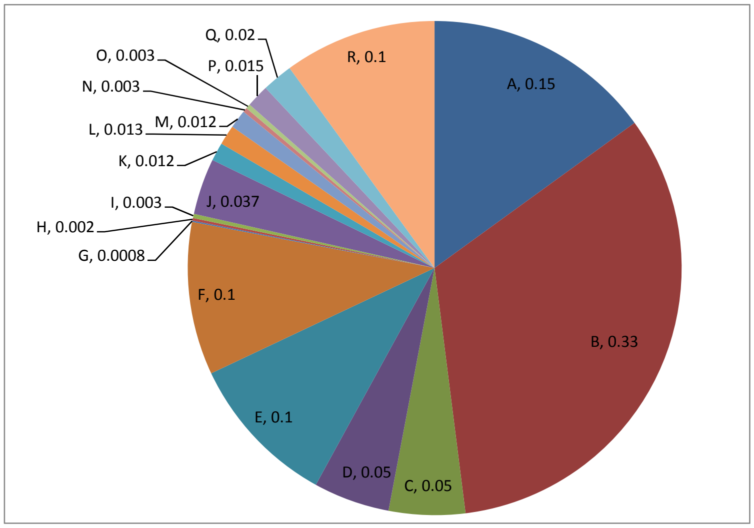
FIGURE ES-4. ILLUSTRATION OF CUMULATIVE ASSESSMENT TWF APPROACH



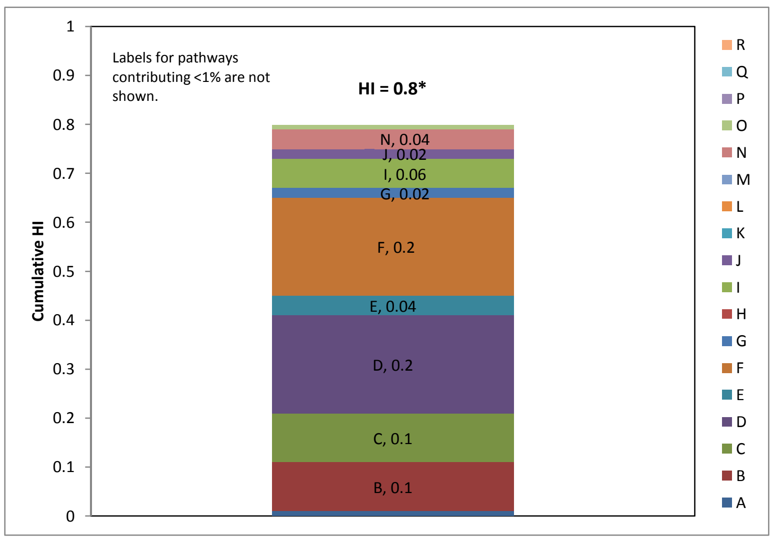
Exposure Scenario		TWF	% of total
A	Outdoor air under ambient conditions	0.2	20%
B	Outdoor air while fishing along the Kootenai River	0.01	1%
C	Indoor air at an OU4 property under active conditions	0.15	15%
D	Indoor air at an OU4 property under passive conditions	0.45	45%
E	Outdoor air at an OU4 property during yard work	0.05	5%
F	Indoor air at the Central Maintenance Building in OU5	0.14	14%
	cumulative:	**1.00**	

FIGURE ES-5. CUMULATIVE ASSESSMENT FOR RECEPTOR EXAMPLE 1

Panel A: Exposure Scenario Contribution to Cumulative TWF



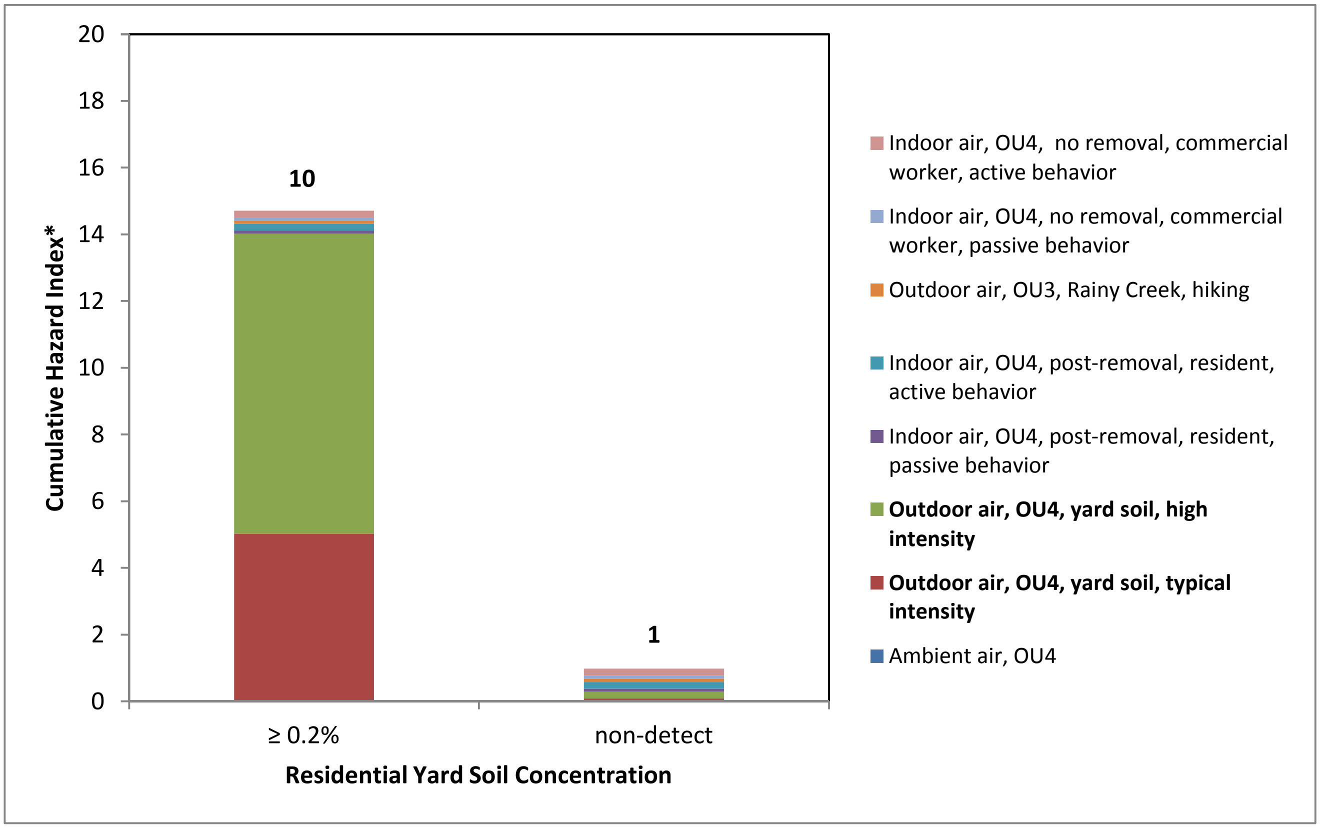
Panel B: Exposure Scenario Contribution to Cumulative HI



	Exposure Scenario	TWF Value	TWF % of total	Risk Estimates Risk	Risk Estimates HQ	Risk Estimates % of total
A	Ambient air, OU4	0.15	15%	2E-07	0.01	1%
B	Indoor air, OU4, post-removal, resident, passive	0.33	33%	2E-06	0.1	13%
C	Indoor air, OU4, post-removal, resident,active	0.05	5%	2E-06	0.1	13%
D	Outdoor air, yard soil, curb-to-curb	0.05	5%	3E-06	0.2	25%
E	Indoor air, OU4, no removal, worker, passive	0.1	10%	7E-07	0.04	5%
F	Indoor air, OU4, no removal, worker, active	0.1	10%	4E-06	0.2	25%
G	Outdoor air, OU4, Libby Middle, student	0.00082	0.08%	3E-07	0.02	3%
H	Outdoor air, OU4, Koot. Valley HS, student	0.0016	0.2%	0E+00	0	0%
I	Outdoor air, OU4, Libby Elem., student	0.0029	0.3%	9E-07	0.06	8%
J	Indoor air, OU4, student, Elem. School	0.037	4%	4E-07	0.02	3%
K	Outdoor air, OU7, Golf course, adult	0.012	1%	0E+00	0	0%
L	Outdoor air, OU4, biking, adult	0.013	1%	0E+00	0	0%
M	Outdoor air, OU5, MotoX, participant	0.012	1%	0E+00	0	0%
N	Outdoor air, OU4, LUA soil, ATV, A	0.0030	0.3%	6E-07	0.04	5%
O	Outdoor air, OU3, forest, hiking, far	0.0030	0.3%	1E-07	0.008	1%
P	Outdoor air, OU3, Kootenai, fishing	0.015	1%	0E+00	0	0%
Q	Outdoor air, OU8, Driving in Libby	0.020	2%	0E+00	0	0%
R	Offsite	0.1	10%	0E+00	0	0%
	cumulative*:	**1.000**		**1E-05**	**0.8**	

* All HQ and HI values are expressed to one significant figure; thus, the height of the bar may appear different from the HI value shown in the table.

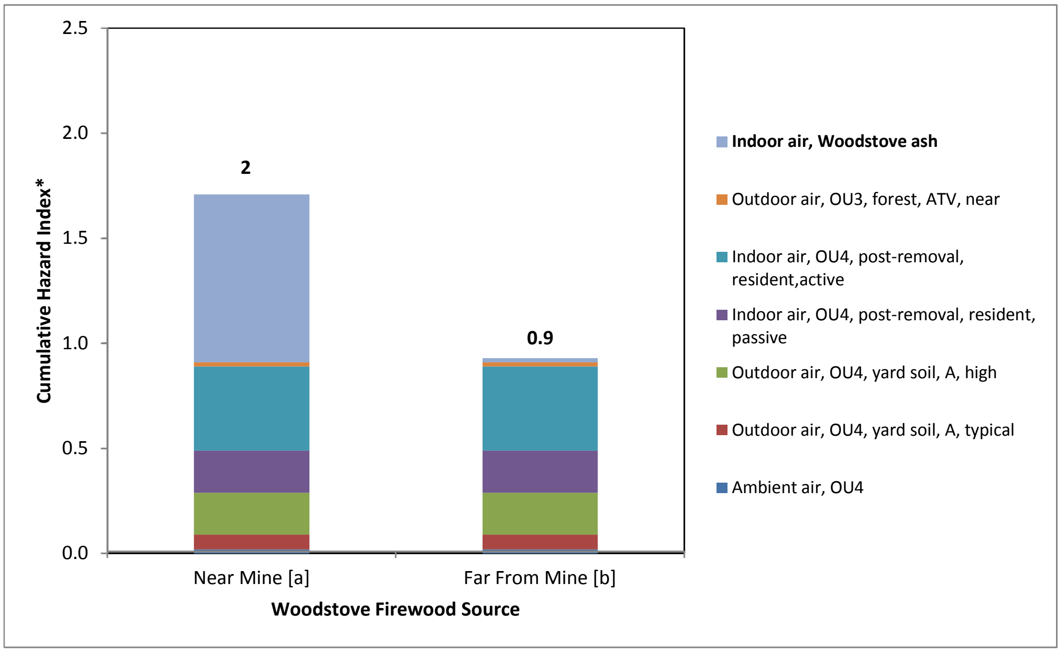
FIGURE ES-6
ILLUSTRATION OF CUMULATIVE HI FOR DIFFERENT YARD SOIL CONCENTRATIONS
Libby Asbestos Superfund Site



* All HQ and HI values are expressed to one significant figure; thus, the height of the bar may appear different from the HI value shown.

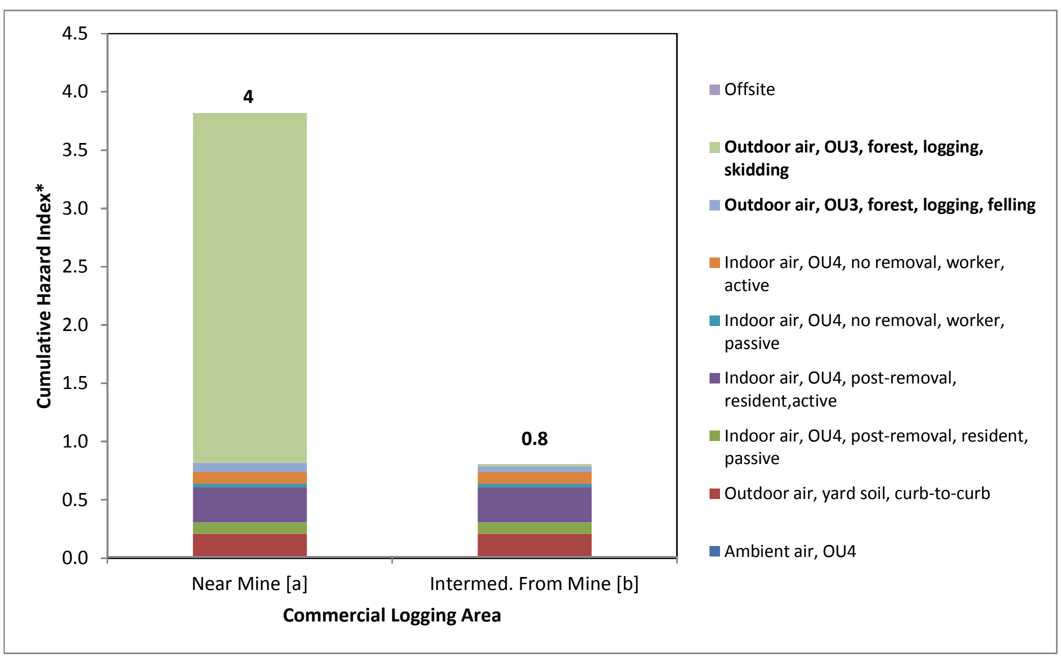
FIGURE ES-7
ILLUSTRATION OF CUMULATIVE HI FOR DIFFERENT ACTIVITY LOCATIONS
Libby Asbestos Superfund Site

Panel A: Woodstove Firewood Source



[a] Near mine: firewood collected approximately one mile downwind of the mine site
[b] Far from mine: firewood collected approximately 10 miles south of Libby and outside the current NPL boundary

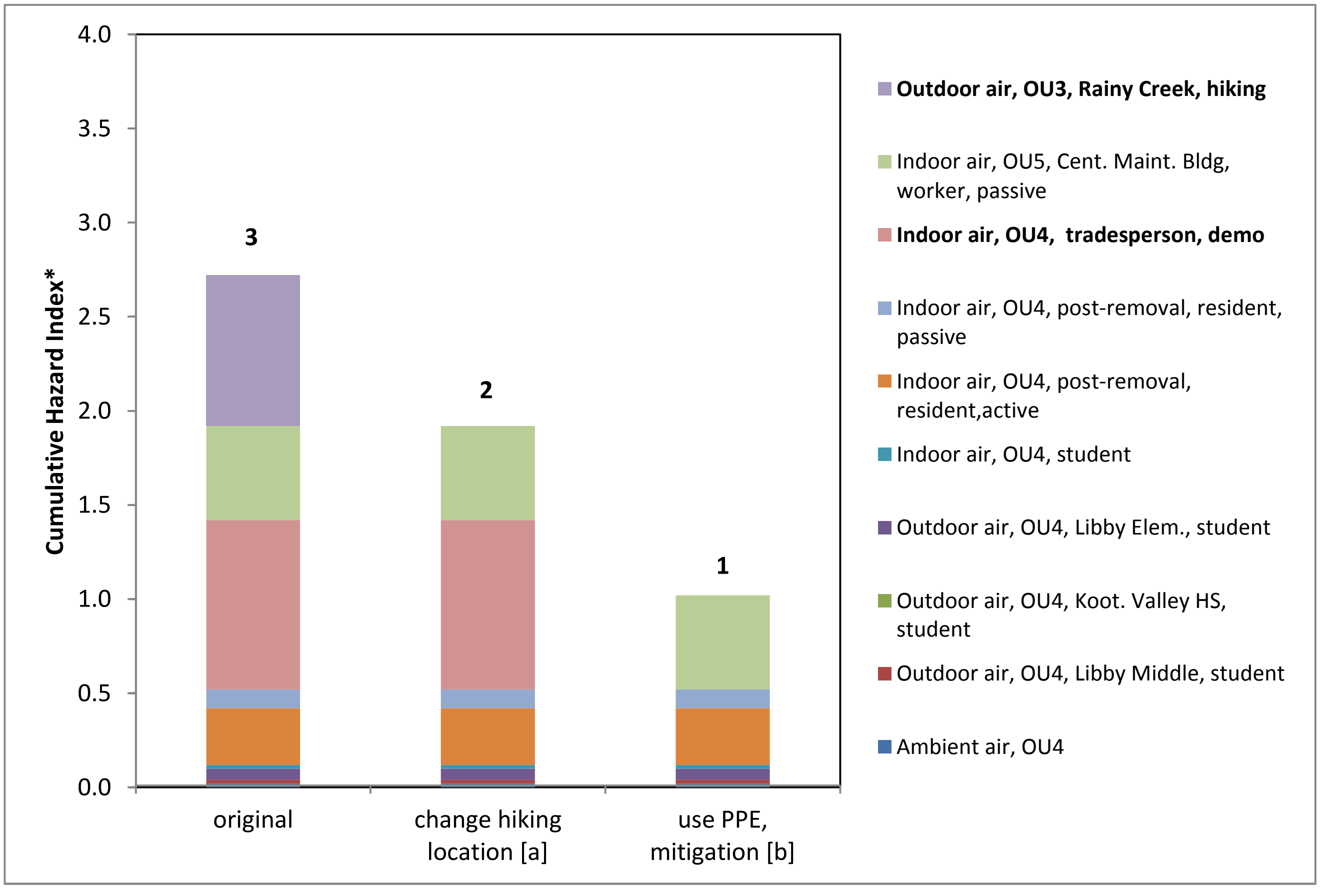
Panel B: Commercial Logging Area



[a] Near mine: Logging activities performed within 1 mile of the mine
[b] Intermed. from mine: Logging activities performed about 4 miles from the mine

* All HQ and HI values are expressed to one significant figure; thus, the height of the bar may appear different from the HI value shown.

FIGURE ES-8
ILLUSTRATION OF CUMULATIVE HI CHANGE WHEN ADDRESSING MAIN RISK DRIVERS
Libby Asbestos Superfund Site



[a] Change hiking location from along Rainy Creek to along the Kootenai River

[b] Use appropriate personal protective equipment and employ dust mitigation measures during tradesperson demolition activities

* All HQ and HI values are expressed to one significant figure; thus, the height of the bar may appear different from the HI value shown.

TABLE ES-1
Conceptual Site Model, Exposure Pathways and Populations
Libby Asbestos Superfund Site

Exposure Media	Exposure Locations	Operable Unit	Disturbance Description	Exposure Population[a]					
							Worker		
				Resident	Recreational Visitor	Teachers/ students	Indoor Worker	Tradesperson	Outdoor Worker
Outdoor air, ambient conditions	Outdoor	All	---	●	●	●	●	●	●
Outdoor air, during soil/duff disturbance activities	Parks	OU1, OU4, OU7	lawn/park maintenance						●
			park use		●				
	Road ROW	OU2, OU8	mowing/brush-hogging						●
	Kootenai River	OU2, OU3	hiking on trails/paths		●				
			fishing/boating		●				
	Mine Site, Rainy Creek	OU3	hiking, tresspassing		●				
	Forested Areas	OU3, OU4	hiking		●				
			building campfires		●				
			ATV riding		●				
			USFS forest maintenance						●
			cutting firelines						●
	Residential/Commercial Properties	OU2, OU4, OU7	yard work	●					●
			gardening	●					●
			playing on driveways	●					
			ATV riding in LUAs	●					
	Schools	OU4, OU7	outdoor maintenance						●
			playing on playgrounds			●			
	Bike Trails/Paths	OU4, OU5, OU7	riding bicycles		●				
	Roads	OU3, OU8	driving cars	●	●	●	●	●	●
	Motocross Track	OU5	motocross participant/spectator		●				
	Industrial Properties	OU5	site maintenance						●
	Railyard/Railroad Corridors	OU6	RR maintenance						●
Outdoor air, during tree bark disturbance activities	Forested Areas	OU3, OU4	local wood harvesting	●					
			commercial logging						●
			campfire burning		●				
			wildfire	●	●	●	●	●	●
	Landfills	OU4, OU7	woodchipping						●
Outdoor air, during woodchip/mulch disturbance activities	Residential/Commercial Properties	OU2, OU4, OU7	gardening/landscaping	●					●
	Woodchip Piles	OU5	pile maintenance						●
Indoor air, passive conditions	Residential/Commercial Properties	OU4, OU7	---	●			●		
	Industrial Properties	OU5	---				●		
	Schools	OU4, OU7	---			●			
Indoor air, during VI disturbance activities	Residential/Commercial Properties	OU4, OU7	attic use, routine property maintenance	●				●	
			construction/demolition					●	
Indoor air, during indoor dust disturbance activities	Residential/Commercial Properties	OU4, OU7	cleaning (sweeping, dusting, vacuuming)	●					
	Commercial/Industrial Buildings	OU1, OU5	general				●		
	Schools	OU4, OU7	general			●			
Indoor air, during woodstove ash disturbance activities	Residential/Commercial Properties	OU4, OU7	woodstove ash removal	●					

[a] Note that a given individual may be a member of several exposure populations. For example, an individual may live in OU7, work in OU4, and recreate in OU3. In this example, aspects of the exposure scenarios for a resident, indoor worker, and recreational visitor would apply to the individual. The cumulative assessment addresses cumulative exposures that span multiple exposure scenarios.

Notes:

ATV - all-terrain vehicle
LUAs - limited-use areas
OU - operable unit
ROW - right-of-way
USFS - United States Forest Service
VI - vermiculite insulation
RR - railroad

TABLE ES-2
Estimated Risks from Residential Exposures to LA During Soil Disturbance Activities
Libby Asbestos Superfund Site

Location	Exposure Scenario & Soil Concentration	Yard ABS Script Intensity	EPC Mean Air Conc. (PCME LA s/cc)+	RME Exposure Parameters ET (hours/day)	EF (days/year)	ED (years)	TWF	Cancer Risk	Non-cancer HQ
Libby (OU4)	**Yards (Mowing, Raking, Digging)**								
	Non-detect	**high intensity**	0.0040	0.3	60	50	0.0015	**1E-06**	**0.07**
		typical intensity	0.00011	6.3	60	50	0.031	**6E-07**	**0.04**
							TOTAL	**2E-06**	**0.1**
	Trace (<0.2%)	**high intensity**	0.061	0.3	60	50	0.0015	**2E-05**	**1**
		typical intensity	0.0024	6.3	60	50	0.031	**1E-05**	**0.8**
							TOTAL	**3E-05**	**2**
	≥ 0.2%	**high intensity**	0.21	0.3	60	50	0.0015	**5E-05**	**3**
		typical intensity	0.0080	6.3	60	50	0.031	**4E-05**	**3**
							TOTAL	**9E-05**	**6**
	Gardens (Rototilling)								
	Trace (<0.2%)	---	0.039	2	2	50	0.00033	**2E-06**	**0.1**
	Gardens (Digging)								
	Non-detect	---	0.00020	3.3	40	50	0.011	**4E-07**	**0.02**
	Trace (<0.2%)	---	0.00066	3.3	40	50	0.011	**1E-06**	**0.08**
	≥ 0.2%	---	0	3.3	40	50	0.011	**0E+00**	**0**
	Driveway (Playing & Digging)								
	Non-detect	---	0	2	225	15	0.011	**0E+00**	**0**
	Trace (<0.2%)	---	0.0057	2	225	15	0.011	**1E-05**	**0.7**
	≥ 0.2%	---	0.0050	2	225	15	0.011	**9E-06**	**0.6**
	LUAs (ATV-riding)								
	Non-detect	---	0.0012	2	20	50	0.0033	**7E-07**	**0.04**
	Trace (<0.2%)	---	0.0014	2	20	50	0.0033	**8E-07**	**0.05**
Troy (OU7)	**Yards (Mowing, Raking, Digging)**								
	Non-detect	**typical intensity**	0.000062	6.6	60	50	0.032	**3E-07**	**0.02**
	Trace (<0.2%)	**typical intensity**	0	6.6	60	50	0.032	**0E+00**	**0**
	Residential, Outdoor Gardens (Digging & Rototilling)++								
	Non-detect	---	0.000023	5.3	42	50	0.018	**7E-08**	**0.005**
	Trace (<0.2%)	---	0	5.3	42	50	0.018	**0E+00**	**0**
	Residential, Outdoor Driveway (Playing & Digging)								
	Non-detect	---	0.000079	2	225	15	0.011	**1E-07**	**0.01**
	Trace (<0.2%)	---	0.000085	2	225	15	0.011	**2E-07**	**0.01**

+ Concentrations have been adjusted to account for filter preparation method (see Section 2.3.4)
++ Exposure time and frequency have been summed because the EPC is based on a combination of the activities.

Notes:

ABS - activity-based sampling
ATV - all- terrain vehicle
Conc. - concentration
CTE - central tendency exposure
ED - exposure duration
EF - exposure frequency
EPC - exposure point concentration
ET - exposure time
HQ - hazard quotient
LA - Libby amphibole asbestos
LUA - limited use areas
PCME - phase contrast microscopy - equivalent
RME - reasonable maximum exposure
s/cc - structures per cubic centimeter
TWF - time-weighting factor
% - percent
< - less than

Section 1
Introduction

The report presents the Site-wide human health risk assessment (HHRA) for the Libby Asbestos Superfund Site (Site) in Libby, Montana. This risk assessment uses available data to estimate the health risks to people who may breathe asbestos in air, either now or in the future, at the Site. The methods used to evaluate human health risks from asbestos are in basic accordance with U.S. Environmental Protection Agency (EPA) guidelines for evaluating risks at Superfund sites (EPA 1989), including guidance, the *Framework for Investigating Asbestos-Contaminated Superfund Sites (Asbestos Framework)* (EPA 2008a), that has been specifically developed to support evaluations of exposure and risk from asbestos.

1.1 Site Background

Libby is a community in northwestern Montana that is located near a former vermiculite mine (**Figure 1-1**). Vermiculite is a naturally-occurring silicate mineral that exhibits a sheet-like structure similar to mica (**Figure 1-2**). When heated, water molecules between the sheets change to vapor and cause the vermiculite to expand like popcorn into a light porous material (**Figure 1-2**). This process of expanding vermiculite is termed “exfoliation” or “popping.” Both unexpanded and expanded vermiculite have a range of commercial applications, the most common of which include packing material, attic and wall insulation, various garden and agricultural products, and various cement and building products.

The vermiculite mine near Libby began limited operations in the 1920s and was operated on a larger scale by the W.R. Grace Company (Grace) from approximately 1963 to 1990. Operations at the mine included mining and milling of the vermiculite ore. After milling, concentrated ore was transported down Rainy Creek Road by truck to a screening facility (known today as the former Screening Plant) adjacent to Montana Highway 37, near the confluence of Rainy Creek and the Kootenai River (**Figure 1-3**). Here the ore was size-sorted and transported by rail or truck to processing facilities in Libby and nationwide. At the processing plants, the ore was exfoliated by rapid heating and exported to market by rail or truck.

Historic maps show the location of a processing plant at the edge of the former Stimson Lumber Mill, near present day Libby City Hall. This older processing plant was taken off-line and demolished sometime in the early 1950s. Another processing plant (known today as the former Export Plant) was located near downtown Libby, near the intersection of the Kootenai River and Montana Highway 37 (**Figure 1-3**). Expansion operations at the Export Plant ceased sometime prior to 1981, although site buildings were still used to bag and export milled ore until 1990.

During mine operations, invoices indicate shipment of nearly 10 billion pounds of vermiculite from Libby to processing centers and other locations. Most of this was shipped and used within the United States and was often sold under the brand name Zonolite (**Figure 1-2**). Vermiculite material was used in a variety of commercial products that were marketed and sold to the general public. Before the mine closed in 1990, Libby produced approximately 80 percent (%) of the world’s supply of vermiculite.

While the mine was in operation, the milling process released airborne particulates into the atmosphere (**Figure 1-4**). In addition, waste products and off-specification materials were made available to the general public. Further, vermiculite products were used in numerous private residences, businesses, and public buildings across the Site. Vermiculite insulation (VI), both commercially purchased and/or obtained otherwise, was used frequently in Libby buildings. In the course of various Site investigations, EPA has encountered vermiculite used as an additive in mortar, plaster, and concrete; as insulation in attic and walls; in soils at depth around septic tanks, tree roots, underground pipe trenches, building foundations; and in surface soils in gardens, yards, driveways, and play areas (EPA 2014a).

1.2 Basis for Concern

Vermiculite from the mine near Libby contains varying concentrations of asbestos. Asbestos is the generic name for a group of naturally-occurring magnesium silicate minerals that crystallize in long thin fibers. The basic chemical unit of asbestos is $[SiO_4]^{-4}$. This basic unit consists of four oxygen atoms at the apices of a regular tetrahedron surrounding and coordinated with one silicon ion (Si^{+4}) at the center. The silicate tetrahedra can bond to one another through the oxygen atoms, leading to a variety of crystal structures. Based on crystal structure, asbestos minerals are usually divided into two groups: serpentine and amphibole. The only asbestos mineral in the serpentine group is chrysotile. There are several minerals in the amphibole group that occur in the asbestiform habit, including actinolite, tremolite, winchite, richterite, amosite (cummingtonite/grunerite), anthophyllite, and crocidolite (riebeckite). EPA's Toxic Substances Control Act identifies six types of regulated asbestiform varieties of asbestos: chrysotile, crocidolite, amosite, anthophyllite, tremolite, and actinolite.

The vermiculite deposit near Libby contains a distinct form of naturally-occurring amphibole asbestos that is comprised of a range of mineral types and morphologies (see **Figure 1-2**). In the spring of 2000, the U.S. Geological Survey (USGS) performed electron probe micro-analysis and x-ray diffraction analysis of 30 samples collected from asbestos veins at the mine (Meeker *et al.* 2003). The results indicated that there were several mineral varieties of amphibole asbestos present, including (in order of decreasing abundance) winchite, richerite, and tremolite, with lower levels of magnesio-riebeckite, edenite, and magnesio-arfvedsonite. Although Meeker *et al.* (2003) did not report the presence of actinolite, the authors note that, depending on the valence state of iron and data reduction methods utilized by other analytical laboratories, some minerals may also be classified as actinolite. The mixture of asbestos present at the Site is referred to as Libby amphibole asbestos or LA[2].

Historical mining, milling, and processing operations, as well as bulk transfer of mining-related materials, tailings, and waste to locations throughout the Kootenai Valley, are known to have resulted in releases of LA to the environment. Epidemiological studies revealed that workers at the mine had an increased risk of developing asbestos-related lung disease (McDonald *et al.* 1986a, 1986b, 2004; Amandus and Wheeler 1987; Amandus *et al.* 1987a,b; Whitehouse 2004; Sullivan 2007). Additionally, radiographic abnormalities were observed in 17.8% of the general population of Libby, including former workers, family members of workers, and other residents of Libby and Troy, Montana (Peipins *et al.* 2003; Whitehouse *et al.* 2008; Antao *et al.* 2012; Larson *et al.* 2010, 2012a, 2012b). Although the

[2] The *Toxicological Review for Libby Amphibole Asbestos* (EPA 2014c) uses the acronym LAA.

mine ceased operations in 1990, historical or continuing releases of LA from mine-related materials could be serving as a source of ongoing exposure and risk to individuals at the Site.

The Site includes homes and businesses that may have become contaminated with LA as a result of the vermiculite mining and processing conducted in and around Libby, as well as other areas that may have been affected by mining-related releases of LA. In addition to vermiculite mining and processing activities, LA contamination also occurred as a consequence of use of LA-contaminated vermiculite as building insulation in residential and commercial buildings and as soil amendments (e.g., gardens and flowerbeds), use of LA-contaminated building materials (e.g., mortar, chinking), and other uses.

1.3 Regulatory History

In November 1999, EPA responded to requests from the State of Montana, Lincoln County Health Board to investigate the potential exposure to asbestos related to the former mine operations and vermiculite processing. The initial investigation revealed that there were a large number of cases of asbestos-related diseases centered around Libby and that significant amounts of asbestos-contaminated vermiculite still remained in and around Libby (EPA 2000a).

Under Section 104 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), EPA has the authority to complete both removal and remedial actions. Initial actions taken under removal authority began at the former processing areas (Screening Plant and Export Plant) in May 2000 (EPA 2000a). As additional areas requiring removal were identified, such as Rainy Creek Road, residential/commercial properties in Libby, and schools in Libby, the initial Site action memorandum has been amended (EPA 2002a; 2006a, b; 2008b; 2009a, b). Nearly all removal activities performed at the Site since 2000 have been conducted using removal action authority to facilitate the timely removal of LA-contaminated materials. Remedial actions have been completed at the former processing areas; EPA is in the process of evaluating what remedial actions are necessary outside of the former processing areas to address potential LA exposures.

In October 2002, the Libby Site was listed on the National Priorities List (NPL), making it eligible to receive additional federal funds for investigation and removals. In 2009, for the first time in the history of the federal government, EPA and the Department of Human Health Services declared a Public Health Emergency in Libby to provide federal health care assistance for victims of asbestos-related disease.

1.4 Site Operable Units

For long-term management purposes, the Site has been divided into eight operable units (OUs):

- **OU1, Former Export Plant** - This OU is defined geographically by the parcel of land that included the former Export Plant and the Highway 37 embankments, and is situated on the south side of the Kootenai River, just north of the downtown area of the City of Libby. The property is bound by the Kootenai River on the north, the Burlington Northern and Santa Fe (BNSF) railroad thoroughfare on the south, and residential properties on the east and west.

- **OU2, Former Screening Plant** - This OU includes areas impacted by contamination released from the former Screening Plant. These areas include the former Screening Plant, the Flyway property, the Highway 37 right-of-way (ROW) adjacent to the former Screening Plant and/or Rainy Creek Road, and privately-owned properties. The Kootenai Bluff Subdivision area (the

former Grace railroad loading station area), located directly across the Kootenai River from the former screening plant, was removed from OU2 and is now part of OU4.

- **OU3, Mine** – This OU is defined as the property in and around the Zonolite Mine owned by Grace or Grace-owned subsidiaries (excluding OU2) and any area (including any structure, soil, air, water, sediment, or receptor) impacted by the release and subsequent migration of hazardous substances and/or pollutants or contaminants from such property, including, but not limited to, the mine property, the Kootenai River and sediments therein, Rainy Creek, Rainy Creek Road and areas in which tree bark is contaminated with such hazardous substances and/or pollutants and contaminants.
- **OU4, Libby Residential/Commercial Areas -** OU4 is defined as residential, commercial, industrial (not associated with Grace mining operations), and public properties, including schools and parks, in and around the City of Libby, or those properties that have received material from Grace.
- **OU5, Former Stimson Lumber Mill -** This OU is defined geographically by the parcel of land that included the former Stimson Lumber Company. OU5 is bounded by the high bank of Libby Creek to the east, the Kootenai River to the north, and properties within OU4 to the south and west. This OU is currently occupied by various vacant structures/buildings as well as multiple operating businesses (e.g., lumber processing, log storage, excavation contractor). Within the OU5 boundary is the Libby Groundwater Superfund Site, which is not associated with the Libby Asbestos Superfund Site.
- **OU6, BNSF Railroad** - This OU is owned and operated by the BNSF railroad, and is defined geographically by the BNSF property boundaries from the eastern boundary of OU4 to the western boundary of OU7 and extent of contamination associated with the Libby and Troy rail yards.
- **OU7, Town of Troy** – This OU includes all residential, commercial, and public properties in and around the Town of Troy, located 20 miles west of downtown Libby.
- **OU8, Roadways** – This OU is comprised of the United States and Montana State Highways and ROWs within the OU4 and OU7 boundaries.

Figure 1-5 provides a map of the boundaries for each OU. Official boundaries have been established in the records of decision (RODs) for OU1 and OU2 (EPA 2010a, b). Official boundaries for the other OUs (OU3-OU8) will not be determined until the OU-specific RODs are published (the boundaries shown in the figure are "study boundaries" that will be finalized once the OU-specific RODs are published).

1.5 Document Purpose

This document estimates potential risks to people from exposure to LA at the Site. Because people may be exposed by multiple exposure scenarios, often across multiple OUs, potential exposures and risks are evaluated on a Site-wide basis, to provide a representation of potential cumulative exposures. Results of this risk assessment are intended to help inform Site managers and the public about the magnitude of potential risks attributable to LA and to guide the selection of final remedial actions for the Site.

This risk assessment differs from other "typical" Superfund risk assessments. Typically, a risk assessment is conducted as part of a remedial investigation (RI) and evaluates the potential exposures associated with the environmental contamination to determine if any action is warranted to mitigate risk. However, extensive interior and exterior removal actions have been conducted at the Site for more than 10 years, prior to the completion of the risk assessment, to allow for the timely removal of LA contamination while awaiting the necessary exposure and toxicity data needed complete a quantitative assessment of human health risk. Therefore, the purpose of this Site-wide risk assessment is to help risk managers determine if past removal actions have been sufficient to mitigate risk, if additional remedial actions are necessary to address risks, and if so, which exposure pathways would need to be addressed in future remedial actions.

This risk assessment does not seek to quantify potential risks for specific individuals, but evaluates exposures for various receptor populations under numerous exposure scenarios. This document is intended only to assess potential risks; discussions and recommendations on how to manage potential risks will be provided in the Site feasibility study (FS). The selection of Site remedial action levels, which will guide future remediation efforts, will be provided in the OU-specific RODs[3].

1.6 Document Organization

In addition to this introduction, this document is organized as follows:

- **Section 2 –** This section presents the exposure assessment. This section presents a conceptual model of site contamination, identifies the human exposure scenarios of potential concern, and describes the approach for measuring human exposures to asbestos and calculating quantitative exposure estimates.
- **Section 3 –** This section presents the toxicity assessment. This section summarizes the cancer and non-cancer health effects associated with asbestos exposure and identifies the toxicity values that will be used to estimate cancer risk and non-cancer hazard.
- **Section 4 –** This section summarizes the risk characterization approach that will be used to quantify cancer risks and non-cancer hazards to humans exposed to LA at the Site.
- **Section 5 –** This section presents the quantitative estimates of cancer risk and non-cancer hazard to humans exposed to LA in outdoor ambient air at the Site.
- **Section 6 –** This section presents the quantitative estimates of cancer risk and non-cancer hazard to humans exposed to LA in outdoor air during soil/duff disturbance activities.
- **Section 7 –** This section presents the quantitative estimates of cancer risk and non-cancer hazard to humans exposed to LA during disturbances of wood-related materials (e.g., tree bark, mulch, wood chips, woodstove ash generated from firewood).
- **Section 8 –** This section presents the quantitative estimates of cancer risk and non-cancer hazard to humans exposed to LA in indoor air at the Site.

[3] The RODs are already complete for OU1 and OU2. Two separate FS reports will be prepared for OU3 and OU4-OU8, respectively. OU-specific RODs for the remaining OUs will be issued after the FS reports are finalized.

- **Section 9 –** This section presents a cumulative risk assessment. This section describes the approach used to quantify cumulative exposures and summarizes estimates of cancer risk and non-cancer hazard across multiple exposure pathways.
- **Section 10 –** This section presents the uncertainty assessment, and discusses the sources of uncertainty in the risk estimates for human receptors.
- **Section 11 –** This section presents the overall risk assessment conclusions.
- **Section 12 –** This section provides full citations for all EPA guidance documents, reports, analytical methods, Site-related documents, and scientific publications referenced in this HHRA.

All referenced tables, figures, and appendices are provided at the end of this document.

Section 2

Exposure Assessment

Exposure is the process by which receptors come into contact with contaminants in the environment. This section summarizes the exposure media, exposure pathways, and human populations of potential concern at the Site. This section also describes how LA exposures were quantified and the derivation of the exposure point concentrations (EPCs) used in the risk characterization.

People may be exposed to LA by two exposure routes: inhalation and ingestion. Of these two exposure routes, inhalation exposure of LA is considered to be of greatest concern. To the extent that ingestion exposures may occur at this Site (e.g., ingestion of LA in drinking water or food), the added risk from ingestion is expected to be negligible compared to the risk from inhalation. As such, this exposure assessment and subsequent risk calculations focus only on inhalation pathways of exposure. **Appendix A** provides additional information regarding potential risks from LA ingestion exposures.

2.1 Conceptual Site Model

Figure 2-1 presents the conceptual site model (CSM) that depicts how LA in source media can be transported in the environment to exposure media that humans may encounter at the Site. **Table 2-1** summarizes the inhalation exposure pathways and populations that will be evaluated in the HHRA. The main elements of the CSM are discussed below.

2.1.1 Source Media and Exposure Media

As discussed above, vermiculite from the mine contains varying concentrations of LA. Historical mining, milling, and processing operations, use of vermiculite in building materials, transport of mining-related materials, tailings, and waste, and runoff from the mine site are known to have released LA to the environment (see **Figure 2-1**). There have been numerous studies conducted at the Site which demonstrate that LA has been detected in a variety of source media, including indoor dust, VI in walls and attics, soil, tree bark and duff[4] in the forested areas, various wood products (e.g., wood chips, mulch), ash resulting from wood burning, surface water, and sediment. Detailed information on the levels of LA in source media at the Site are summarized in the OU-specific RI reports and data summary reports (EPA 2009c, d, 2014a; CDM Federal Programs Corporation [CDM Smith] 2013a; HDR Engineering, Inc. [HDR] 2013a, b; Kennedy/Jenks Consultants 2014; Tetra Tech EM Inc. [Tetra Tech] 2010, 2012a, 2013, 2014; MWH Americas, Inc. 2014).

However, asbestos fibers in source materials are typically not inherently hazardous, unless the asbestos is released from the source material into air where it can be inhaled (EPA 2008a). Asbestos fibers may become airborne in a number of ways. This may include natural forces, such as wind blowing over a contaminated soil, or human activities that disturb contaminated sources, such as soil or indoor dust. The two main types of exposure media are indoor air and outdoor air.

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[4] Duff consists of the un-decomposed twigs, needles, and other vegetation and the layer of partially- to fully-decomposed litter that occurs on top of the mineral soil in forested areas.

For indoor air, exposures are stratified based on the nature of the disturbance – under "passive" (ambient) conditions and under "active" disturbances of various source media that may be encountered in an indoor setting (i.e., VI, surficial dust, woodstove ash). Similarly, for outdoor air, exposures are stratified based on the nature of the disturbance – under ambient conditions and under active disturbances of various source media that may be encountered in an outdoor setting (i.e., soil/duff, tree bark, woodchips/mulch).

As illustrated in **Figure 2-1**, there are eight general types of exposure media that will be evaluated in the risk characterization when assessing inhalation exposures:

- Outdoor air, under ambient conditions
- Outdoor air, during soil/duff disturbance activities
- Outdoor air, during tree bark disturbance activities
- Outdoor air, during woodchip/mulch disturbance activities
- Indoor air, under passive conditions
- Indoor air, during VI disturbance activities
- Indoor air, during dust disturbance activities
- Indoor air, during woodstove ash disturbance activities

2.1.2 Exposure Pathways and Populations

The amount of LA in air, and hence the amount inhaled, will vary depending on the level of LA in the exposure medium, which can vary from location to location, and the intensity and duration of the disturbing force. Because of this, it is convenient to stratify inhalation exposure pathways according to the disturbance activity and the location where the disturbance activity occurs. **Table 2-1** summarizes the exposure locations and general types of disturbances that may occur for each of the eight exposure media identified in **Figure 2-1**. It is recognized that not every possible disturbance activity is included in **Table 2-1**. The list of disturbance activities included is intended to be representative of the types of activities that are expected to occur more frequently and/or that have a higher potential for LA release. As shown, exposures to outdoor air under soil/duff disturbances are the most complex because the types of activities that may disturb soil/duff are so varied, ranging from playing on playgrounds and driveways, to hiking in the forest, to mowing lawn areas in parks.

Table 2-1 identifies several potential exposure populations that are evaluated quantitatively in the risk assessment, including residents, recreational visitors, teachers/students, and several types of workers. The types of exposures that are expected for each population are discussed below.

- **Residents** – By definition, residential exposures are expected to occur at residential properties located in OU4 and OU7. Expected residential exposure pathways include both indoor and outdoor exposures to source materials at the residence (e.g., indoor dust, VI, soil, woodstove ash). Residents may also be exposed while engaging in local wood harvesting in the forested areas of the Site or while driving on roads and alleys in Libby and Troy.

- **Recreational visitors** – The primary types of exposure for a recreational visitor are related to outdoor exposure scenarios under a wide variety of activities that may disturb soil, duff, and tree bark. These recreational activities may include, but are not limited to, use of local parks, riding bicycles along trails and paths, hiking, camping, and riding all-terrain vehicles (ATVs) in the forested areas, fishing and boating along creeks and rivers, and riding motorcycles at the local motocross (MotoX) track (in OU5).

- **Teachers/students** – Teacher and student exposures are expected to occur at schools located in OU4 and OU7 and include both indoor and outdoor exposure pathways. Indoor exposures would occur inside school classrooms and in common areas (e.g., hallways, cafeteria, gymnasium), while outdoor exposures are mainly related to exposures while playing on playgrounds and athletic fields.

For workers, several different types of workers are delineated based on the types of exposure pathways that may be encountered while engaging in day-to-day occupational activities:

- **Indoor worker** – Examples of indoor workers include office administrative assistants, shop keepers, and restaurant staff. Exposures are expected to occur mainly inside buildings located in OU1, OU4, OU5, and OU7. The primary types of exposures expected for these workers are related to indoor exposure scenarios, during both passive conditions and under active disturbances of indoor dust.

- **Tradesperson** – Local tradespeople are a special type of indoor worker that are evaluated separately due to the increased frequency of potential exposures to VI or other asbestos-containing building materials. Examples of tradesperson exposures include an electrician accessing attics or crawlspaces for re-wiring, a plumber cutting holes in walls/ceilings, and a general contractor performing remodeling. The types of exposures expected for a tradesperson are related to indoor exposure scenarios, under active disturbances of VI or other asbestos-containing building materials during occupational activities. Although exposures may also occur during passive conditions, these are likely to be minor compared to active disturbance scenarios described above.

- **Outdoor worker** – The types of exposures expected for an outdoor worker are related to exposure scenarios under a wide variety of activities that may disturb soil/duff, tree bark, and woodchips/mulch at the Site. These occupational activities may include, but are not limited to, Montana Department of Transportation (MDT) workers performing mowing/brush-clearing along highway ROWs, maintenance workers mowing/weed-trimming at parks and schools, BNSF workers performing railroad maintenance, U.S. Forest Service (USFS) employees conducting forest maintenance activities, local landfill workers chipping accumulated wood waste, and commercial loggers in the forested areas near the Site.

All exposure populations are assumed to have exposures to outdoor ambient air and outdoor air[5] while driving cars on Site roads. In the event of a wildfire, all exposure populations are assumed to have exposures to smoke in outdoor air derived from wildfires that may occur in forested areas at the Site.

[5] For the purposes of the risk assessment, air inside vehicles is evaluated as outdoor air that may be influenced by disturbances of soil (e.g., airborne roadway dust).

Note that a given individual may be a member of several exposure populations. For example, an individual may live in Troy (OU7), work at a business in Libby (OU4), and recreate in the forest near the mine (OU3). In this example, aspects of the exposure scenarios for a resident, indoor worker, and recreational visitor would apply to the individual. The cumulative assessment addresses exposures that span multiple exposure scenarios (see Section 9).

2.2 Exposure Parameters

For every exposure pathway of potential concern, it is expected that there will be differences between different individuals in the level of exposure at a specific location due to differences in exposure time, exposure frequency, and exposure duration. Thus, there is normally a wide range of average daily exposures between different individuals of an exposed population. Because of this, all exposure calculations must specify what part of the exposure range is being estimated. Typically, attention is focused on exposures that are "average" or are otherwise near the central portion of the range, and on exposures that are near the upper end of the range (e.g., the 95th percentile). These two exposure estimates are referred to as central tendency exposure (CTE) and reasonable maximum exposure (RME), respectively. Both CTE and RME receptors will be evaluated in the HHRA.

When selecting CTE parameters, the exposure parameters for a specific exposure pathway (i.e., exposure time, exposure frequency, exposure duration) are usually based on mean or median values, such that the CTE represents the "typical" or "average" exposure. When selecting RME parameters, the exposure parameters are selected such that the combination of the exposure parameters results in a "reasonable maximum" estimate of the daily exposure (EPA 1989).

EPA has collected a wide variety of data to establish default exposure parameter values for use in HHRAs (EPA 1989, 1991a, 1993, 1996, 2014b), and EPA's *Exposure Factors Handbooks* (EPA 2008c, 2011) provide information on activity-specific exposure patterns. Established default values were utilized in this HHRA when available. However, as appropriate, exposure parameters were adjusted to be Site-specific. For example, the default residential RME exposure frequency is 350 days per year (EPA 1991a), but for the purposes of evaluating exposures during soil disturbances, this default value was adjusted to reflect Site conditions and account for days when releases due to soil disturbance activities were unlikely, either due to snow cover or high soil moisture content (from November through March). Site-specific surveys have been conducted for several exposure scenarios (see **Appendix G**). Various groups and stakeholders have provided input on the selection of exposure parameters for selected receptor populations (e.g., Libby school administrators provided information on student, teacher, and maintenance worker exposures, the USFS provided input on forest-related exposure scenarios). If default or Site-specific values were not available, professional judgment was used in selecting appropriate exposure parameter values.

The selected exposure parameters for each exposure pathway evaluated in this risk assessment are discussed and presented in each risk characterization section (Section 5 through Section 9).

2.3 Exposure Point Concentrations

2.3.1 Approach for Determining Exposure Concentrations

Previous investigations conducted at the Site have demonstrated that LA is present in a variety of environmental media. However, the detection of LA in a source medium, such as soil, tree bark, or indoor dust, does not necessarily indicate that human exposures to LA released to air during disturbances of these media would result in unacceptable exposures or risks. The amount of LA that could be released to air and inhaled will vary depending upon a number of factors, including the level

of LA in the source medium, the nature, intensity, and duration of the disturbance activity, meteorological conditions (e.g., relative humidity, wind direction, and speed), and conditions of the source medium (e.g., soil moisture content, vegetation coverage). Because of this, predicting the LA levels in air based on measured LA levels in source media is extremely difficult. For this reason, EPA recommends an empiric approach for investigating asbestos-contaminated Superfund sites, where concentrations of asbestos in air from source disturbances are measured rather than predicted (EPA 2008a). This type of sampling is referred to as activity-based sampling (ABS) and involves the collection of air samples under representative source-disturbance conditions that can be used to calculate inhalation exposures and potential risks (EPA 2008a). This sampling methodology is similar to the exposure assessment methods used by the National Institute of Occupational Safety and Health (NIOSH) to monitor worker exposures.

It is not possible to perform an ABS study to evaluate every possible type of source-disturbance activity that could be performed at every location on the Site. Therefore, Site ABS investigations have focused on characterizing those activities that are representative of typical activities that may be performed by various receptor populations that disturb source media. To date, more than two dozen different ABS investigations have been conducted at the Site to evaluate potential exposures to LA from disturbances of source media. These studies have included a wide range of activities in every OU, including, but not limited to, dusting and vacuuming inside residences in OU4 and OU7, raking/mowing/digging in yard soil in OU4 and OU7, hiking and riding ATVs in OU3, commercial logging operations in OU3, biking in OU4 and OU5, performing railroad maintenance activities in OU6, and performing brush-clearing activities along roads in OU8.

Table 2-2 summarizes the ABS investigations that have been conducted at the Site which provide measured data on LA concentrations in ABS air that will be utilized in this HHRA. As shown, more than 3,100 ABS air samples have been collected at the Site since 2001. These ABS investigations have evaluated LA levels in air during disturbances of a variety of source media, including outdoor soil/duff (Panel A), various wood products (i.e., bark, mulch, wood chips, ash resulting from wood burning) (Panel B), and indoor sources (e.g., dust and VI) (Panel C). **Figure 2-2** provides example photographs of some of the types of ABS activities that have been conducted at the Site. The results of each investigation are discussed further in Section 5 through Section 8.

2.3.2 Methods for Measuring and Reporting Air Concentrations

Asbestos data reduction and interpretation methods differ from traditional chemistry methods. Understanding the differences in asbestos data reduction and interpretation methods is key to the proper use of asbestos data for site characterization and risk assessment. **Appendix B** provides a detailed discussion of basic concepts for asbestos sampling, analysis, and data reduction, including an overview of asbestos sampling and analysis methods, Poisson statistics, how to characterize uncertainty for individual samples, how samples are ranked as detect or non-detect, the differences between the analytical sensitivity and the detection limit, how to calculate the mean across multiple samples (i.e., treatment of non-detects), and issues associated with estimating the uncertainty bounds around the mean.

2.3.2.1 Overview of Sampling and Analysis Methods

Experience at the Site and at other asbestos sites has demonstrated that personal air samples (i.e., samples that collect air in the breathing zone of a person) tend to provide a better estimate of human exposures to LA in air than samples collected by a stationary monitor (EPA 2007a), especially if the person is engaged in an activity that disturbs an asbestos source. Thus, most of the ABS exposure estimates used in this risk assessment are based on personal air samples collected during simulated

disturbance activities. These personal ABS air samples are collected by drawing a known volume of air through a filter that is located in the breathing zone of the individual performing the disturbance activity (see **Figure 2-2**) and determining the number of LA structures that become deposited on the filter surface.

In the past, the most common technique for analyzing asbestos on air filters was phase contrast microscopy (PCM). In this technique, the filter is examined in accordance with NIOSH Method 7400, Issue 2 (NIOSH 1994) and all structures that have a length greater than (>) 5 micrometers (µm) and an aspect ratio (the ratio of length to width) of 3:1 or greater are counted as "PCM fibers". The limit of resolution of PCM is about 0.25 µm (NIOSH 1994), so structures thinner than this are generally not observable.

A key limitation of PCM is that structure discrimination is based only on size and shape. Because of this, it is not possible to distinguish between asbestos and non-asbestos structures. For this reason, EPA (2008a) recommends the analysis of air samples by transmission electron microscopy (TEM). This method can operate at a higher magnification and is able to detect structures much smaller than can been seen by PCM. In addition, TEM instruments are fitted with accessory detectors that allow each structure to be classified according to asbestos mineral type, meaning that structures can be characterized as either chrysotile or amphibole, and further by amphibole asbestos type (e.g., actinolite, tremolite, crocidolite, amosite).

2.3.2.2 Results Reporting

At the Site, all ABS and ambient air samples have been analyzed by TEM using International Organization of Standardization (ISO) 10312:1995(E) (ISO 1995) counting and recording rules, as modified by Site-specific laboratory modification requirements[6]. During the analysis, detailed information for each observed asbestos structure (e.g., asbestos type, structure type, length, width) is manually recorded on a laboratory bench sheet. Once the analysis is complete, the total number of countable asbestos structures is determined. The concentration of asbestos in air in a given sample is given by:

$$C_{air} = N \cdot S$$

where:

C_{air} = Concentration of asbestos in air (s/cc)

N = Number of asbestos structures observed in the sample (s)

S = Achieved analytical sensitivity (per cubic centimeter of air, cc^{-1})

For air, the achieved analytical sensitivity is calculated as:

$$S = \frac{EFA}{GO \cdot Ago \cdot V \cdot 1000 \cdot F}$$

[6] The Libby-specific TEM ISO 10312 laboratory modifications are maintained on the *Libby Lab* eRoom and are available upon request.

where:

S = Achieved analytical sensitivity (cc^{-1})

EFA = Effective area of the filter (square millimeters [mm^2])

GO = Number of grid openings examined

Ago = Area of a grid opening (mm^2)

V = Volume of air passed through the filter (liters [L])

1000 = Conversion factor (cc/L)

F = F-factor, or fraction of primary filter deposited on secondary filter (if an indirect preparation is necessary; F = 1 for direct preparation)

There is no "preset" lower limit of analytical sensitivity for TEM. The achieved analytical sensitivity will depend upon the number of grid openings examined, and can be improved (i.e., lowered) by examining additional grid openings. Each of the air sampling investigations conducted at the Site have established investigation-specific target analytical sensitivity requirements based on the receptor and exposure scenario being evaluated.

If the sample has been analyzed more than once (e.g., a subsequent supplemental TEM analysis was performed to improve the achieved analytical sensitivity), the "pooled" concentration, which is inclusive of all analyses, is calculated as follows:

$$C_{air,\ pooled} = \sum N_i \,/\, \sum(1/S_i)$$

where:

$C_{air,\ pooled}$ = Pooled concentration of asbestos in air across analyses (s/cc)

N_i = Number of asbestos structures observed in analysis 'i' (s)

S_i = Achieved analytical sensitivity for analysis 'i' (cc^{-1})

2.3.2.3 Definition of PCME

For the purposes of estimating potential human health risks, the concentration of asbestos in air must be expressed in units of PCM fibers. This is because the risk models for estimation of risks from inhalation exposure to LA (EPA 2014c) are based on exposures expressed as PCM f/cc. Estimates of concentration used in this report are based on PCM-equivalent (PCME) structures observed during the TEM analysis. As noted above, in the PCM method (NIOSH 1994), a structure is counted as a PCM fiber if it has a length longer than 5 µm and an aspect ratio greater than or equal to (≥) 3:1. Although there is no thickness rule specified in the PCM method, particles thinner than about 0.25 µm are not usually detectable by PCM (see **Appendix C**). Hence, the TEM counting rules for PCME structures are: length > 5 µm, width ≥ 0.25 µm, and aspect ratio ≥ 3:1. Note that the upper width cut-off of 3 µm specified by EPA (2008a) has not been used, because structures wider than 3 µm are counted by the NIOSH PCM method (NIOSH 1994). This basis of this width criterion change is discussed in more detail in **Appendix C**.

Figure 2-3 graphically illustrates the concept of PCME. This figure summarizes the recorded dimensions of all LA structures observed during TEM analyses[7] of air samples collected at the Site. Only those structures within the area shaded in green of the figure meet PCME counting rules. As illustrated, about 35% of all LA structures observed in air samples rank as PCME.

In this risk assessment, all air concentrations are reported as PCME LA s/cc. Although TEM analyses may have occasionally observed and recorded other amphibole asbestos types (e.g., anthophyllite) and/or chrysotile structures, exposures and risks are calculated for LA only, as this is the type of asbestos that is expected to be Site-related.

2.3.3 Approach for Calculating Exposure Point Concentrations

An exposure point (also referred to as an exposure unit or exposure area) is an area where exposure and risk are to be evaluated. It is assumed that random exposure occurs over the entire exposure area; thus, the risk is related to the mean concentration across the entire exposure area (EPA 1992). An EPC is an estimate of the average concentration of LA in air at the exposure area.

Ideally, the EPC used in the risk calculations for each exposure location would be the true average concentration within the exposure area, averaged across the exposure duration. However, the true average concentration at a location can only be approximated from a finite set of measurements, and the observed sample mean might be either higher or lower than the true mean.

To minimize the chances of underestimating the true level of exposure and risk, EPA generally recommends that risk calculations be based on the 95% upper confidence limit (95UCL) of the sample mean (EPA 1992). However, as discussed in **Appendix B**, there is no EPA-approved method for calculating the 95UCL for asbestos datasets[8]. Thus, in accordance with EPA guidance (EPA 2008a), risk calculations presented in the risk characterization utilize the sample mean. The sample mean is an unbiased estimate of the true concentration, but the true concentration may be either higher or lower. The potential magnitude of the difference between the sample mean and the true mean cannot presently be quantified. The uncertainty assessment (Section 10) provides additional information on the uncertainty that arises from use of the sample mean.

Note that, when computing the arithmetic mean of a set of air samples, all samples with a count of zero asbestos structures (non-detects) are evaluated using a concentration value of zero (EPA 2008a). This is important, because assigning any value greater than zero to such samples may tend to bias the sample mean high (EPA 1999, 2008a). This concept is demonstrated in **Appendix B**.

In some cases, all air samples within a dataset were non-detect. In these instances, the mean air concentration (i.e., a concentration of zero) was used as the EPC in the risk calculations. The uncertainty assessment (Section 10) provides additional information on risk estimates for datasets where all samples are non-detect.

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[7] Restricted to analyses performed under high magnification (20,000x) using TEM ISO 10312 (ISO 1995) recording rules.

[8] The equations and functions in ProUCL (EPA 2010c) are not designed for asbestos datasets and application of ProUCL to asbestos datasets is not recommended (EPA 2008a).

2.3.4 Adjustment for Indirect Preparation Methods

Collected air filters are examined at the laboratory prior to analysis to determine if the filter can be prepared directly or if an indirect preparation is necessary. Indirect preparation is required if there is uneven loading, if the filter is considered overloaded (particulate coverage of greater than 25% on the filter), or if there is loose material in the cowl of the air cassette. If an air filter can be prepared directly, the filter is prepared for analysis by TEM in basic accordance with the filter preparation methods provided in International Organization of Standardization (ISO) 10312 (ISO 1995).

If an indirect preparation is required, the filter is prepared (usually with ashing) in accordance with the indirect filter preparation procedures in the Site-specific standard operating procedure (SOP) EPA-LIBBY-08. If ashing is not performed, the indirect preparation procedure in the SOP EPA-LIBBY-08 is similar to ISO 13974 (ISO 1999), except that the total solution volume is increased from 40 milliliters (mL) to 100 mL (to allow for the preparation of a series of indirect filters with different volumes) and to retain a portion of the original filter for archive. If ashing is performed, the indirect preparation procedure in the SOP EPA-LIBBY-08 is similar to American Society for Testing and Materials (ASTM) D-5755 (ASTM 2009), with the addition of an ashing of the entire primary filter. In brief, the ashed residue from the original filter is suspended in water and sonicated. An aliquot of this water is applied to a second filter, which is then used to prepare a set of TEM grids. Reported air concentrations for indirectly prepared samples incorporate a dilution factor, or F-factor (see Section 2.3.2.2 for the air concentration equation).

For chrysotile asbestos, indirect preparation often tends to substantially increase structure counts due to dispersion of bundles and clusters (Hwang and Wang 1983; Health Effects Institute-Asbestos Research [HEI-AR] 1991; Breysse 1991). For amphibole asbestos, the effects of indirect preparation are generally much smaller (Bishop *et al.* 1978; Sahle and Laszlo 1996; Harris 2009). Site-specific studies on the effect of indirect preparation on reported LA air concentrations show that indirect preparation usually increased reported PCME LA air concentrations, but the concentrations were within a factor of about 2-4 compared to direct preparation (Berry *et al.* 2014; Goldade and O'Brien 2014). The relative insensitivity of PCME LA air concentration estimates to indirect preparation methods is likely due to the fact that, unlike chrysotile, complex LA structures (e.g., bundles, clusters) that might be subject to dispersal during an indirect preparation are not common in Libby air samples (EPA 2010g).

Because the PCM data used to derive toxicity factors for inhalation exposure to LA (EPA 2014c) are based on filters that were prepared directly for analysis in accordance with PCM methods, and to avoid potentially biasing calculated EPCs high due to the effect of indirect preparation, the reported PCME LA concentration for any air sample that was prepared using indirect preparation was adjusted by a factor of 2.5 (Berry *et al.* 2014) as follows:

$$C_{adj} = C_{indirect} / 2.5$$

where:

C_{adj} = Air concentration, adjusted for indirect preparation (PCME LA s/cc)

$C_{indirect}$ = Reported air concentration for an indirectly prepared filter (PCME LA s/cc)

2.5 = Indirect preparation adjustment factor

Appendix D provides more information on the frequency of indirect preparation for each of the datasets used in the risk assessment.

2.3.5 Calculated Exposure Point Concentration Values

As noted previously, there have been numerous investigations conducted at the Site to evaluate potential exposures to LA from various exposure pathways. These investigations have included ambient air monitoring programs and a variety of indoor and outdoor ABS studies to evaluate LA releases during disturbances of source materials (see **Table 2-2**).

The applicable datasets and calculated EPCs for each exposure pathway evaluated in this risk assessment are discussed and presented in Section 5 through Section 8. **Appendix E** provides the detailed analytical results for all samples that were used in this HHRA. **Appendix D** provides a data quality assessment of the datasets that were used to calculate exposures and risks.

Section 3

Toxicity Assessment

The objective of a toxicity assessment is to identify what adverse health effects a contaminant may cause, and how the occurrence of those adverse effects depends on exposure level. The toxicity assessment is divided into two parts: the first characterizes and quantifies the carcinogenic (cancer) effects, while the second addresses the non-cancer effects. This two-part approach is employed because there are typically major differences in the shape of the exposure-response curve for cancer and non-cancer effects.

A detailed summary of the cancer and non-cancer effects of asbestos is provided in the Agency for Toxic Substances and Disease Registry (ATSDR) *Toxicological Profile for Asbestos* (ATSDR 2001) and in EPA's *Airborne Asbestos Health Assessment Update* (EPA 1986). A detailed summary of effects related specifically to LA is provided in the *Toxicological Review for Libby Amphibole Asbestos* (EPA 2014c). The following sections provide a summary of the cancer and non-cancer effects from exposure to asbestos in general and LA in particular.

3.1 Cancer Effects

3.1.1 Lung Cancer

Exposure to asbestos is associated with increased risk of developing all major histological types of lung carcinoma (adenocarcinoma, squamous cell carcinoma, and oat-cell carcinoma) (ATSDR 2001). The latency period for lung cancer generally ranges from about 10 to 40 years (ATSDR 2001). Early stages are generally asymptomatic, but as the disease develops, patients may experience coughing, shortness of breath, fatigue, and chest pain. Most lung cancer cases result in death. The risk of developing lung cancer from asbestos exposure is substantially higher in smokers than in non-smokers (Selikoff *et al.* 1968; Doll and Peto 1985; ATSDR 2001; National Toxicology Program [NTP] 2005).

3.1.2 Mesothelioma

Mesothelioma is a tumor of the thin membrane that covers and protects the internal organs of the body, including the lungs and chest cavity (pleura), and the abdominal cavity (peritoneum). Exposure to asbestos is associated with increased risk of developing mesothelioma (ATSDR 2001). The latency period for mesothelioma is typically around 20 to 40 years (Lanphear and Buncher 1992; ATSDR 2001; Mossman *et al.* 1996; Weill *et al.* 2004). By the time symptoms appear, the disease is most often rapidly fatal (British Thoracic Society 2001).

3.1.3 Other Cancers

A number of studies suggest asbestos exposure may increase risk of cancer at various gastrointestinal sites (EPA 1986). The National Academy of Science (NAS) reviewed evidence regarding the role of asbestos in gastrointestinal cancers primarily following occupational exposures (these are assumed to be primarily by the inhalation route) (NAS 2006). NAS concluded that data are "suggestive, but insufficient" to establish that asbestos exposure causes stomach or colorectal cancer. Data on esophageal cancer are mixed and were regarded as "inadequate to infer the presence or absence of a causal relationship to asbestos exposure".

Data on risks of gastrointestinal cancer following ingestion-only exposure are more limited. Some researchers (Conforti *et al.* 1981; Kjaerheim *et al.* 2005) have reported a significant correlation between oral exposure to asbestos in drinking water and the risk of gastrointestinal cancer. The World Health Organization (WHO 1996) concluded that data are not adequate to support the hypothesis that an increased cancer risk is associated with the ingestion of asbestos in drinking water. However, EPA has determined that there is an increased risk of developing benign intestinal polyps as a consequence of long-term ingestion of asbestos-contaminated drinking water. This finding is the basis for the maximum contaminant level (MCL) for asbestos in drinking water (EPA 1988). See **Appendix A** for additional information on the evaluation of ingestion exposures at the Site.

NAS (2006) reviewed available data on the relationship between asbestos exposure and laryngeal cancer and concluded that the data were "sufficient to infer a causal relationship between asbestos and laryngeal cancer." NAS (2006) concluded that data are "suggestive but not sufficient to infer a causal relationship between asbestos exposure and pharyngeal cancer."

Excess deaths from kidney cancer among persons with known exposure to asbestos have been reported by a number of researchers (Selikoff *et al.* 1979; Puntoni *et al.* 1979; Enterline *et al.* 1987). A review by Smith *et al.* (1989) evaluated these studies and concluded that asbestos should be regarded as a probable cause of human kidney cancer.

In a recent review, the International Agency for Research on Cancer (IARC) added ovarian cancer to the organ sites associated with asbestos exposure (IARC 2012).

3.1.4 Cancer Effects Observed in People Exposed to LA

A number of studies indicate that exposure to LA increases the risk of lung cancer and mesothelioma in humans. Amandus and Wheeler (1987), Amandus *et al.* (1987a,b), McDonald *et al.* (1986a, 2004), Sullivan (2007), and Larson *et al.* (2010) studied the cause of death in workers exposed to LA while working at the vermiculite mine and mill at Libby. All of these groups of researchers reported an increased incidence of lung cancer and mesothelioma in exposed workers, strongly supporting the conclusion that LA can cause increased risk of respiratory cancer when inhaled. In a follow-on investigation of workers from the O.M. Scott facility in Marysville, Ohio, three cases of mesothelioma have been reported (Dunning *et al.* 2012). This facility utilized vermiculite ore that originated from the vermiculite mine in Libby from 1959 to 1980.

3.2 Non-cancer Effects

3.2.1 Asbestosis

Asbestosis is a chronic pneumoconiosis associated with inhalation exposure to asbestos. It is characterized by the gradual formation of scar tissue in the lung parenchyma. Initially, the scarring may be minor and localized within the basal areas, but as the disease develops, the lungs may develop extensive diffuse alveolar and interstitial fibrosis (American Thoracic Society [ATS] 2004).

Build-up of scar tissue in the lung parenchyma results in a loss of normal elasticity in the lung, which can lead to the progressive loss of lung function. The initial symptoms of asbestosis are shortness of breath, particularly during exertion. People with fully-developed asbestosis tend to have increased difficulty breathing that is often accompanied by coughing or rales. In severe cases, impaired respiratory function can lead to death.

Asbestosis generally takes a long time to develop, with a latency period from 10 to 20 years. Mossman and Churg (1998) suggest that latency is inversely proportional to exposure level. The disease may continue to progress long after exposure has ceased (ATSDR 2001). The progression of the disease after cessation of exposure also appears to be related to the level and duration of exposure (ATS 2004).

3.2.2 Pleural Abnormalities

Exposure to asbestos may increase the risk of several types of abnormalities of the pleura (the membrane surrounding the lungs) (Broaddus *et al.* 2011), including:

- Pleural effusions are areas where excess fluid accumulates in the pleural space. Most pleural effusions last several months, although they may be recurrent (Lockey *et al.* 1984). Pleural effusions can be asymptomatic, although they may be associated with decreased ventilatory capacity, fever, and pain (Bourbeau *et al.* 1990).

- Pleural plaques are acellular collagenous deposits, often with calcification. Pleural plaques represent an irreversible pathological lesion of the pleural membranes. Pleural plaques are the most common manifestations of asbestos exposure (ATSDR 2001; ATS 2004; Rohs *et al.* 2008). Pleural plaques may also be asymptomatic in some, but not all, cases (Bourbeau *et al.* 1990).

- Diffuse pleural thickening (DPT) is a non-circumscribed fibrotic lesion (often described as a "basket weave of collagen") in the pleura that encases the lungs. Thickening may be extensive and cover a whole lobe or even an entire lung. DPT restricts the ability of the lung to expand mechanically, thereby reducing respiratory volume. DPT is strongly associated with reduced lung function (Baker *et al.* 1985; Churg 1986; Jarvholm and Larsson 1988; EPA 2014c). Severe effects are rare, although Miller *et al.* (1983) reported on severe cases of DPT that lead to death.

- Localized pleural thickening (LPT) may include both pleural plaques and pleural thickening that does not involve blunting of the costophrenic angle (the angle between the diaphragm and the chest wall at the bottom of the lung). Thickening of the pleura is due to collagen deposition, and may occur on both the outer and inner surface of the pleura. LPT is generally considered to be a less severe lesion than DPT or asbestosis. However, EPA has performed a detailed review of the literature and concluded that LPT is associated with a decrement in pulmonary function (EPA 2014c).

The latency period for pleural abnormalities is usually about 10 to 40 years (ATS 2004), although pleural effusions may occasionally develop as early as one year after first exposure (Epler and Gaensler 1982).

3.2.3 Other Non-Cancer Effects

Some epidemiological studies provide evidence that chronic exposure to asbestos can increase the risk of several other types of non-cancer effects including cor pulmonale (right-sided heart failure), retroperitoneal fibrosis (a fibrous mass in the back of the abdomen that blocks the flow of urine from the kidneys to the bladder), depressed cell-mediated immunity (ATSDR 2001), and autoimmune disease (Pfau *et al.* 2005; Noonan *et al.* 2006; Marchand *et al.* 2012; Serve *et al.* 2013; Ferro *et al.* 2014).

3.2.4 Observations of Non-Cancer Diseases in People Exposed to LA

Amandus and Wheeler (1987), McDonald *et al.* (1986a, 2004), and Sullivan (2007) studied the cause of death in workers exposed to LA while working at the vermiculite mine and mill at Libby. Each of these researchers reported that Libby workers were more likely to die of non-malignant respiratory disease (i.e., asbestosis, chronic obstructive pulmonary disease, pneumonia, tuberculosis and emphysema) compared to white males in the general U.S. population.

McDonald *et al.* (1986b) and Amandus *et al.* (1987b) evaluated the prevalence of chest radiographic changes in workers exposed to LA at the vermiculite mine and mill at Libby. These researchers observed increased prevalence in several types of pleural abnormalities, including pleural calcification, pleural thickening, and profusion of small opacities. Rohs *et al.* (2008) studied the prevalence of pleural changes in the lungs of workers exposed to LA at the O.M. Scott facility in Marysville, Ohio, where Libby vermiculite was used as an inert carrier for lawn care products. Rohs *et al.* (2008) observed an increased incidence of pleural plaques (LPT), DPT, and interstitial changes (irregular opacities) in exposed workers. Peipins *et al.* (2003), Muravov *et al.* (2005), and Whitehouse (2004) also observed increased incidence in pleural abnormalities in workers at Libby. Recent continuing research on the Libby workers shows that several pulmonary health outcomes that may affect respiratory function are associated with cumulative fiber exposure levels (Larson *et al.* 2012a).

Community-based studies in Libby have documented the occurrence of a range of asbestos-related non-neoplastic diseases, ranging from pleural plaques (LPT) and DPT to chronic obstructive pulmonary disease (McDonald *et al.* 1986b; Amandus *et al.* 1987a, b; Amandus and Wheeler 1987; ATSDR 2001; Peipins *et al.* 2003; Whitehouse 2004; Sullivan 2007; Larson *et al.* 2010). These diseases affect not only the miners and millers who worked at the Grace facilities, but also community members who lived in Libby and Troy and the surrounding areas. The ATSDR health screening conducted during 2000 and 2001 of over 7,300 Libby community members revealed the presence of significant levels of pleural abnormalities and elevated morbidity and mortality. Continuing medical surveillance of the Libby population by researchers from the ATSDR and Mount Sinai Medical Center reveals pulmonary disorders in young adults who were exposed to asbestos in early childhood (Vinikoor *et al.* 2010) and cardiovascular effects in former miners who experienced high cumulative fiber exposures (Larson *et al.* 2010). Researchers at the University of Montana and Idaho State University have reported elevated levels of autoimmune diseases in the Libby population (Noonan *et al.* 2006; Pfau *et al.* 2008; Marchand *et al.* 2012).

3.3 Toxicity Values

In 1986, EPA utilized data that were available at the time to establish quantitative exposure-response models for both lung cancer and mesothelioma (EPA 1986). These models were based on data from all forms of asbestos, including chrysotile as well as several forms of amphibole asbestos. In the exposure-response models that were developed, the magnitude of cancer risk depended not only on exposure concentration, but also age at first exposure and duration of exposure. EPA (2008a) summarizes the approach and provides a table of inhalation unit risk (IUR) values for a range of different age at first exposure and exposure duration values. This approach is also described on EPA's Integrated Risk Information System (IRIS) web page for asbestos. No method was established at that time for quantification of non-cancer hazards.

More recently, EPA has performed a detailed toxicological review of available studies on the cancer and non-cancer effects specifically associated with exposure to LA. EPA released a draft for public

review and comment in August 2011. EPA's Scientific Advisory Board (SAB) reviewed and commented on the draft report, and issued final review comments in January 2013. EPA revised the draft document in accordance with the SAB comments and issued the final *Toxicological Review of Libby Amphibole Asbestos* in December 2014 (EPA 2014c). This final document provides detailed descriptions of the data and methods used to derive LA-specific values for characterization of both cancer and non-cancer effects. The following sections provide brief summaries of the derivation of these values.

3.3.1 Cancer

Under EPA's *Guidelines for Carcinogen Risk Assessment* (EPA 2005a), LA is classified as being "carcinogenic to humans" following inhalation exposure based on epidemiologic evidence that shows a convincing association between exposure to LA fibers and increased lung cancer and mesothelioma mortality (EPA 2014c). These results are further supported by animal studies that demonstrate the carcinogenic potential of LA fibers in rodent bioassays (EPA 2014c).

EPA (2014c) developed the IUR value for LA based on exposure-response data from workers employed at the vermiculite mining and milling operation in Libby. The IUR for LA is defined as the excess lifetime cancer risk estimated to result from continuous exposure to one PCM fiber of LA per cubic centimeter of air (1 PCM f/cc). In contrast to the approach developed previously (EPA 1986), the cancer exposure-response model selected for LA does not depend on age at first exposure or exposure duration, so only a single IUR value is needed to quantify cancer risk. This LA-specific IUR, referred to as IUR_{LA}, is 0.17 (PCM f/cc)$^{-1}$ (EPA 2014c). This IUR includes the risk of both lung cancer and mesothelioma.

3.3.2 Non-cancer

Non-cancer effects from inhalation exposures to airborne toxicants are generally evaluated by comparing the exposure level at the site of concern to an exposure level (the reference concentration, RfC) that does not result in adverse non-cancer effect. Exposures below the RfC are considered to be without risk of adverse non-cancer health effects, while exposures above the RfC may cause an effect, depending on the exposure level.

The LA-specific RfC, referred to as RfC_{LA}, is defined as an estimate of the exposure concentration that is likely to be without an appreciable risk of adverse health effects in the general population (including sensitive subgroups) following continuous lifetime exposure. The RfC_{LA} was derived from exposure-response data obtained from a cohort of workers employed at the O.M. Scott Plant in Marysville, Ohio (EPA 2014c). LPT was selected as the critical effect endpoint for the derivation of the RfC_{LA}. As noted above, LPT is an irreversible pathological change associated with a statistically and biologically significant decrement in pulmonary function (EPA 2014c). EPA evaluated a wide range of alternative exposure-response models, and ultimately selected a model that depended only on average exposure concentration. The resulting RfC_{LA} is 0.00009 PCM f/cc (EPA 2014c).

The derivation of the RfC_{LA} includes the application of uncertainty factors (UFs) to account for uncertainties in the available data and the exposure-response model. The overall (composite) UF is a factor of 300 (EPA 2014c). The composite UF of 300 is comprised of an intra-species UF of 10 to account for human variability and potentially susceptible individuals, a data-informed subchronic-to-chronic UF of 10 to address uncertainty due to increasing risk of LPT over the course of a lifetime, and a database UF of 3 to account for data deficiencies in the available health effects literature for LA (EPA 2014c).

Section 4

Risk Characterization Approach

4.1 Basic Equations

As described previously in Section 3.3, EPA has recently developed an IUR and an RfC for exposure to LA (EPA 2014c). This section describes how these toxicity factors were used to estimate cancer risks and non-cancer hazards to people who are exposed to LA in air at the Site. The basic equations for evaluating potential cancer and non-cancer risks from inhalation exposures to LA are provided below.

4.1.1 Cancer

The basic equation used to estimate excess lifetime cancer risk from inhalation exposures to LA under a range of differing exposure scenarios is as follows:

$$Risk_s = \bar{C}_{LT,s} \cdot IUR_{LA}$$

where:

$Risk_s$ = Lifetime excess risk of developing cancer (lung cancer or mesothelioma) as a consequence of inhalation exposure to LA for the specific exposure scenario "s" being assessed.

$\bar{C}_{LT,s}$ = Lifetime average exposure concentration (PCME s/cc) associated with exposure scenario "s"

IUR_{LA} = LA-specific lifetime inhalation unit risk $(PCM\ s/cc)^{-1}$

For exposure scenarios in which exposure is not continuous over a lifetime, the value of $\bar{C}_{LT,s}$ is calculated by adjusting the scenario-specific exposure concentration (EPC_s, PCME s/cc) by a scenario-specific time-weighting-factor (TWF_s) that accounts for the less-than-continuous exposure:

$$\bar{C}_{LT,s} = EPC_s \cdot TWF_s$$

where:

EPC_s = Exposure point concentration of LA in air (PCME LA s/cc). The EPC is an estimate of the long-term average concentration of LA in inhaled air for the specific exposure scenario "s" being assessed.

TWF_s = Time-weighting factor. The value of the TWF term ranges from zero to one, and describes the average fraction of a lifetime during which exposure occurs from the specific exposure scenario "s" being assessed.

Combining these equations yields:

$$Risk_s = EPC_s \cdot TWF_s \cdot IUR_{LA}$$

Excess cancer risk can be expressed in several formats. A cancer risk expressed in a scientific notation format as 1E-06 is equivalent to 1 in 1,000,000 (one in a million) or $1x10^{-6}$. Similarly, a cancer risk of 1E-04 is equivalent to 1 in 10,000 (one in ten thousand) or $1x10^{-4}$. For the purposes of this risk assessment, all cancer risks are presented in a scientific notation format (i.e., 1E-04) and expressed to one significant figure (EPA 1989).

The derivation of cumulative cancer risk estimates (the total cancer risk to a receptor resulting from exposure to LA across multiple exposure scenarios) is presented in Section 9.

4.1.1.1 Exposure Point Concentrations

Section 2.3 provides a detailed discussion of the methods used in deriving EPCs for LA. As noted previously, although other amphibole asbestos types and/or chrysotile may have been noted in some air samples, exposures and risks are calculated for LA only, as this is the type of asbestos that is expected to be Site-related.

The applicable datasets and calculated EPCs for each exposure scenario evaluated in this risk assessment are discussed and presented in Section 5 through Section 8. **Appendix E** provides the detailed analytical results for all samples that are used in this HHRA. **Appendix D** provides a data quality assessment of the datasets that are used to calculate exposures and risks.

4.1.1.2 Time-Weighting Factor for Cancer

As noted previously (see Section 3.3.1), the IUR_{LA} is defined as the excess cancer risk estimated to result from <u>continuous lifetime</u> exposure to 1 f/cc. Exposures at the Site are estimated for a lifetime. Since there are multiple exposure scenarios that occur during a lifetime, it is necessary to evaluate the contribution of each source to the total lifetime exposure. Therefore, each exposure scenario was evaluated as a fraction of the total lifetime exposure by adjusting the scenario-specific EPCs using a scenario-specific TWF.

The value of the TWF for cancer exposures is calculated as:

$$TWF_s = ET_s/24 \cdot EF_s/365 \cdot ED_s/70$$

where:

ET_s = Exposure time (hours per day) that the exposed person is engaged in exposure scenario “s”

EF_s = Exposure frequency (days per year) the exposed person is engaged in exposure scenario “s”

ED_s = Exposure duration (years) the exposed person is engaged in exposure scenario “s”

As noted above, the TWF_s ranges from zero to one, and describes the average fraction of a lifetime (70 years) during which asbestos exposure from scenario “s” occurs. It is important to note that the derivation of the TWF presented above differs from the approach described in EPA (2008a) in that the TWF equation includes the ED term. This is because the approach developed by EPA (1986) and detailed in EPA (2008a) accounts for differing exposure durations by adjusting the IUR term rather than the TWF term.

The calculated TWFs for each exposure scenario evaluated in this risk assessment are discussed and presented in Section 5 through Section 8. *TWFs for the evaluation of cumulative exposures, across multiple exposure pathways, are determined using a modification of this methodology (see Section 9).*

4.1.1.2 LA-specific Inhalation Unit Risk Value

As discussed in Section 3.3.1, the IUR_{LA} is 0.17 (PCM f/cc)$^{-1}$ and is derived from a cohort of workers employed at the vermiculite mine in Libby (EPA 2014c). It is important to understand that the IUR_{LA} is not age- or duration-dependent; thus, the less-than-lifetime IUR derivation procedures presented in Appendix E of EPA (2008a) do not apply when using the LA-specific cancer toxicity value.

4.1.2 Non-cancer

The basic equation used to characterize non-cancer hazard from inhalation exposures to LA under a range of differing exposure scenarios is as follows:

$$HQ_s = \bar{C}_{LT,s} \;/\; RfC_{LA}$$

where:

HQ_s = Hazard quotient from inhalation exposure to LA for the specific exposure scenario “s” being assessed.

$\bar{C}_{LT,s}$ = Lifetime average exposure concentration (PCME s/cc) associated with exposure scenario “s”

RfC_{LA} = LA-specific reference concentration (PCM s/cc)

For exposure scenarios in which exposure is not continuous over a lifetime, the value of $\bar{C}_{LT,s}$ was calculated by adjusting the scenario-specific exposure concentration (EPC_s, PCME s/cc) by the scenario-specific time-weighting-factor (TWF_s) that accounts for the less-than-continuous exposure:

$$\bar{C}_{LT,s} = EPC_s \cdot TWF_s$$

where:

EPC_s = Exposure point concentration of LA in air (PCME LA s/cc). The EPC is an estimate of the long-term average concentration of LA in inhaled air for the specific exposure scenario “s” being assessed.

TWF_s = Time-weighting factor. The value of the TWF term ranges from zero to one, and describes the average fraction of a lifetime during which exposure occurs from the specific exposure scenario “s” being assessed.

Combining these equations yields:

$$HQ_s = EPC_s \cdot TWF_s \;/\; RfC_{LA}$$

The derivation of cumulative non-cancer hazard index (HI) estimates (the hazard resulting from exposure of a receptor across multiple exposure scenarios) is presented in Section 9. All non-cancer

HQs and HIs are expressed to one significant figure. This approach is consistent with EPA guidance (EPA 1989) and mathematical principles for expressing numerical significance, as the RFC_{LA} is also expressed to one significant figure.

4.1.2.1 Exposure Point Concentrations

The EPCs used to calculate non-cancer hazards are the same as those used to calculate cancer risks (see Section 4.1.1.1).

4.1.2.2 Time-Weighting Factor for Non-Cancer

As noted previously (see Section 3.3.2), the RfC_{LA} is defined as an estimate of the exposure concentration that is likely to be without an appreciable risk of adverse health effects in the general population (including sensitive subgroups) following continuous lifetime exposure. Exposures at the Site are estimated for a lifetime. Since there are multiple exposure scenarios that occur during a lifetime, it is necessary to evaluate the contribution of each source to the total lifetime exposure. Therefore, each exposure scenario was evaluated as a fraction of the total lifetime exposure by adjusting the scenario-specific EPCs using a scenario-specific TWF.

$$\bar{C}_{LT,s} = EPC_s \cdot TWF_s$$

The scenario-specific TWF values used at the Site for non-cancer exposures were calculated using the same equation as described above for cancer:

$$TWF_s = ET_s/24 \cdot EF_s/365 \cdot ED_s/70$$

Notice that this approach differs from the approach that is generally used for other (non-asbestos) inhalation toxicants (EPA 2009e) in that the averaging time is assumed to be 70 years, rather than setting the averaging time equal to ED. This is because the approach developed by EPA (2009e) was derived mainly to evaluate hazards from volatile organic compounds, and was not intended for application to durable fibers that remain in the lung and continue to trigger biological responses long after exposure has ceased. Rather, EPA (2009e) recommends that EPA's Technical Review Workgroup (TRW) for Asbestos be consulted when evaluating risks from inhalation exposure to asbestos. The approach above was evaluated and approved for use at the Site by the Asbestos TRW (EPA 2014d).

4.1.2.1 LA-specific Reference Concentration

As discussed in Section 3.3.2, the RfC_{LA} is 0.00009 PCM f/cc and is derived from a cohort of workers from an O.M Scott plant that utilized vermiculite ore which originated from the vermiculite mine in Libby. LPT was selected as the critical effect endpoint for the derivation of the RfC_{LA} (EPA 2014c).

4.2 Sensitive Effects Endpoint

For most chemicals that cause both cancer and non-cancer effects, cancer is usually the endpoint that drives risk management decisions. That is, as exposure concentration increases, the cancer risk estimate reaches EPA's threshold of 1E-04 before the non-cancer HQ reaches a threshold of 1. However, this is not the case for LA exposures. For LA, for any given exposure scenario, non-cancer effects are the more sensitive endpoint. This observation (which is specific to LA) is derived from the basic equations for non-cancer HQ and cancer risk presented above, as follows:

$$HQ_s = EPC_s \cdot TWF_s / RfC_{LA}$$

$$Risk_s = EPC_s \cdot TWF_s \cdot IUR_{LA}$$

$Risk_s/HQ_s = IUR_{LA} \cdot RfC_{LA} = 0.17 \cdot 0.00009 = 1.5E\text{-}05$

Thus, for LA, when the non-cancer HQ is 1, the excess cancer risk is approximately 1E-05.

4.3 Risk Characterization Approach and Organization

As illustrated in **Figure 2-1**, there are eight general types of exposure scenarios that were evaluated in the risk characterization:

- Outdoor air, under ambient conditions (see Section 5)
- Outdoor air, during soil/duff disturbance activities (see Section 6)
- Outdoor air, during tree bark disturbance activities (see Section 8)
- Outdoor air, during woodchip/mulch disturbance activities (see Section 8)
- Indoor air, under passive conditions (see Section 7)
- Indoor air, during VI disturbance activities (see Section 7)
- Indoor air, during dust disturbance activities (see Section 7)
- Indoor air, during woodstove ash disturbance activities (see Section 8)

As shown in **Table 2-1**, there are multiple types of activities and locations that were evaluated as part of the risk characterization for exposures to air under source-disturbance conditions. In this document, potential exposures and risks for each exposure scenario are presented in Section 5 through Section 8 (as identified above). Within each section, an overview of the applicable air exposure dataset is provided, EPCs are derived, selected exposure parameters and calculated TWFs for each receptor and exposure scenario are presented, and estimated cancer risks and non-cancer HQs are calculated. Section 9 presents a cumulative assessment of potential exposures across multiple exposure media, disturbance activities, and locations for several example cumulative exposure scenarios.

4.4 Risk Interpretation

EPA's Office of Solid Waste and Emergency Response (OSWER) Directive #9355.0-30, "*Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions*" (EPA 1991b) provides guidance on the interpretation of estimated risks. The level of cancer risk that is of concern is a matter of personal, community, and regulatory judgment. In general, EPA considers cumulative excess cancer risks that are below about 1E-06 to be so small as to be negligible, and risks above 1E-04 to be sufficiently large that some form of remedial action is desirable. Excess cancer risks that range between 1E-04 and 1E-06 are generally considered to be acceptable, although this is evaluated on a case-by-case basis, and EPA may determine that risks lower than 1E-04 are not sufficiently protective and warrant remedial action.

For non-cancer, if the cumulative HI is less than or equal to 1, then remedial action is generally not warranted unless there are adverse environmental impacts. If an HI exceeds 1, there is some possibility that non-cancer effects may occur, although an HI above one does not indicate an effect will definitely occur. This is because of the margin of safety inherent in the derivation of all toxicity values

(see Section 3.3.2). However, the larger the HI value, the more likely it is that an adverse effect may occur. Note that risk management decisions generally consider the sum of all the risks contributed by differing exposure scenarios into account, rather than simply evaluating each one independently.

Section 5

Risks from Exposures to Outdoor Ambient Air

Every receptor population at the Site is expected to be exposed to LA in outdoor ambient air. Several air monitoring studies have been conducted to measure LA concentrations in air under "typical" ambient conditions that may be encountered at the Site. The following sections summarize the results of these monitoring studies, describe how these data were used to calculate exposures, present estimated cancer risks and non-cancer HQs from exposures to ambient air, and discuss how air concentrations at the Site compare to levels measured at other offsite locations and to historical Site conditions.

5.1 Data Summary

5.1.1 Overview of Ambient Air Investigations

Since 2006, EPA has conducted outdoor monitoring in Libby to measure LA concentrations in ambient air. As part of this program, 25 different stationary monitors in Libby (the number of monitors varied by year) were sampled across multiple days at regular intervals to provide data on ambient air concentrations of LA (EPA 2006c, 2007b; CDM Smith 2010a, 2011a, 2012a, 2013b). **Figure 5-1** provides a map of the ambient air monitoring stations in Libby. Prior to 2010, the primary focus of this ambient air monitoring program was to measure ambient air concentrations throughout the Libby community (stations L1-L18). Beginning in 2010, the focus of the monitoring program shifted to evaluate ambient air concentrations along transportation corridors in Libby (stations L20-L26 were added, and only stations L8 and L12 continued to be sampled post-2010). In addition, two stationary monitors in Eureka and Helena, Montana were also sampled for the purposes of providing a frame of reference to which observations at the Site could be compared. **Figure 5-2** illustrates the sampling event durations for each ambient air monitor. Detailed results of the ambient air monitoring program in Libby are summarized in EPA (2009f) and EPA (2014e).

The Montana Department of Environmental Quality (DEQ) conducted a similar outdoor ambient air monitoring program in Troy from 2009 to 2013. As part of this program, 18 stationary monitors in Troy were sampled across multiple days at regular intervals to provide data on ambient air concentrations of LA in Troy (Tetra Tech 2009). **Figure 5-3** provides a map of the ambient air monitoring stations in Troy. As shown, the monitoring stations were stratified into four zones. **Figure 5-4** illustrates the sampling event durations for each ambient air monitor in Troy. Detailed results of the ambient air monitoring program in Troy are summarized in eleven *Outdoor Ambient Air Monitoring Study Quarterly Memoranda*[9].

Beginning in late 2013, the Lincoln County Asbestos Resource Program (ARP) took over responsibility for the implementation of the long-term ambient air monitoring programs for Libby and Troy.

[9] Data from the final six sampling events in 2013 have not been summarized in any quarterly memorandum. Copies of all quarterly memoranda are available on EPA's project website: http://www2.epa.gov/region8/libby-asbestos-ou7-outdoor-ambient-air-study-quarterly-reports

Outdoor ambient air sampling was also conducted near the mine site (OU3) during the fall of 2007 and summer of 2008. As part of this sampling program, 12 stationary monitors were sampled across multiple days at regular intervals to provide data on ambient air concentrations of LA near the mine site. Sampling was conducted by Grace's contractors in accordance with EPA-developed sampling and analysis plans (SAPs) (EPA 2007c, 2008d). **Figure 5-5** provides a map of the ambient air monitoring stations near the mine. Detailed results for the ambient air monitors at the mine are summarized in CDM Smith (2013a).

Table 5-1 presents summary statistics of the ambient air monitoring results for each station.

5.1.2 Calculation of EPCs

Figure 5-6 presents the average ambient air concentrations by month across all Libby community monitors (i.e., stations L1-L18). As shown, average LA air concentrations in the Libby community tend to vary temporally, with concentrations tending to be highest in the spring and summer months and lowest in the fall and winter. Because of this temporal variability, and because the sampling frequency has not been equal across months (as seen in **Figure 5-2** and **Figure 5-4**), for the purposes of calculating long-term average exposures over multiple years, the ambient air EPC is calculated using the following approach. First, for a given monitoring location, the average ambient air concentration was calculated for each month across years for which data were available. Then, for each month, the average ambient air concentration was calculated across locations ($\bar{X}_i$). The EPC used in the risk assessment was calculated as follows:

$$EPC = \sum \bar{X}_i \cdot 1/12$$

where:

EPC = Long-term average ambient air exposure point concentration (PCME LA s/cc)

$\bar{X}_i$ = Average ambient air concentration in month 'i' across locations (PCME LA s/cc)

1/12 = One-month weighting factor

As noted above, because the focus of the ambient air monitoring program in Libby shifted in 2010 to focus on monitoring concentrations along transportation corridors, which may yield higher ambient air concentrations than in the general community, EPCs for Libby were calculated separately for stations in the community (L1-L18) and for stations along transportation corridors (L20-L26). For Troy, because there do not appear to be differences in ambient air concentrations by zone (see **Table 5-1**), EPCs were calculated across all stations (regardless of zone). The long-term average EPCs for outdoor ambient air that were used in the risk calculations are presented in **Table 5-2**.

5.2 Exposure Populations and Parameters

Exposure to ambient air occurs during outdoor activities, with the exposure time (hours/day) and frequency (days/year) tending to differ between different receptors and different activity patterns. However, for simplicity, risk estimates from exposures to ambient air were calculated for each exposure area based on the maximally-exposed receptor. (If risks are below a level of concern for the maximally-exposed receptor, it is assumed that risks would also be below a level of concern for other receptors with lower exposures.) For example, although teachers/students, recreational visitors, and workers may all be exposed to LA in ambient air in Libby and Troy, risk estimates were calculated

based on a residential exposure scenario, because this population is likely to have the highest exposure (i.e., the highest TWF). Because residential exposures are not expected in OU3 (i.e., there are no residential properties at the mine site), risk estimates were calculated based on a recreational visitor exposure scenario.

Table 5-3 presents the selected RME and CTE exposure parameters values and calculated TWFs for each receptor type. This table identifies the basis of the selected exposure parameter and notes if any Site-specific adjustments were applied. It is important to note that the exposure parameters and resulting TWFs presented in **Table 5-3** are selected for the purposes of evaluating potential risks from the ambient air exposure pathway only (i.e., the cumulative assessment may utilize different TWFs).

5.3 Risk Estimates

Table 5-4 presents the estimated cancer risks and non-cancer HQs for exposures to LA in outdoor ambient air based on RME (Panel A) and CTE (Panel B). As shown, RME cancer risks are at or below 1E-06 and HQs are below 0.1 for all Site exposure locations; CTE cancer risks and HQs are even lower. These results indicate that exposures to LA in ambient air are not likely to be of concern to individuals at the Site and are not likely to contribute significantly to cumulative risks.

5.4 Comparison to Ambient Air in Other Locations

Asbestos is a naturally-occurring material and has also been widely used in commercial products in the past. Because of this, asbestos fibers are often detectable in air at locations that are not associated with any specific sources.

As noted above, the Libby ambient air monitoring program included sampling locations in Eureka and Helena (see **Table 5-1**) for the purposes of providing a frame of reference to which Site observations could be compared. In Eureka, a total of 32 ambient air sampling events were conducted from October 2006 to September 2007 and all samples were non-detect for PCME LA (mean achieved analytical sensitivity of 0.000037 cc^{-1}). In Helena, a total of 39 ambient air sampling events were conducted from October 2006 to June 2008, and PCME LA was detected in four events, with an average ambient air concentration of about 0.0000054 PCME LA s/cc.

SRC, Inc. (2013a) summarizes data from published reports on the levels of asbestos (all forms of asbestos, including chrysotile) that have been reported in air at a number of locations across the country. Average asbestos concentrations in outdoor ambient air tended to range between about 0.00001 and 0.0004 s/cc, with an overall mean of about 0.00003 s/cc (concentrations are based on structures longer than 5 µm), but there was a high degree of variability observed between individual samples. In general, ambient air concentrations in rural areas tended to be lower than urban areas.

As shown in **Table 5-2**, average ambient air concentrations of LA in the Libby community (0.0000048 PCME LA s/cc) and in Troy (about 0.0000015 PCME LA s/cc) under current conditions are consistent with asbestos levels that have been measured in Eureka and Helena, as well as across the country. The predominant type of asbestos observed in Libby and Troy is LA; the presence of chrysotile fibers has only been noted in about 5% of the ambient air samples collected, and other types of amphibole asbestos (e.g., anthophyllite, crocidolite) have been observed in only five samples (0.3% of all ambient air samples).

5.5 Comparison to Historical Ambient Air in Libby

Very few data are available that provide measured air concentrations under historical conditions within the Libby community. In 1975, when the mine was in operation, ambient air concentrations of 0.67 to 1.5 PCM f/cc were measured in downtown Libby (Grace 1975). Although these results are based on PCM and may be biased high with regard to airborne asbestos concentrations, these data demonstrate that ambient air at the Site under current conditions has significantly improved relative to historical conditions (i.e., current ambient air concentrations are 100,000 times lower).

Section 6

Risks from Exposures During Soil/Duff Disturbances

To date, there have been about 20 different outdoor ABS investigations conducted at the Site to evaluate potential exposures to LA from disturbances of soil/duff. **Table 2-2** (Panel A) summarizes the types of outdoor ABS investigations that have been conducted during soil/duff disturbances for each OU. For most exposure areas, the source medium is soil; however, in forested areas the source medium is likely a mixture of soil and duff materials.

As shown in **Table 2-1**, there is the potential for exposures to LA during disturbances of soil in every OU for a wide range of receptor types and exposure scenarios. Because the exposure scenarios differ by location, each location is evaluated separately, as follows:

- Section 6.1 – Residential and Commercial Properties in OU4 and OU7
- Section 6.2 – Schools and Parks in OU4 and OU7
- Section 6.3 – Trails and Bike Paths in OU4 and OU7
- Section 6.4 – OU1
- Section 6.5 – OU2
- Section 6.6 – OU3
- Section 6.7 – OU5
- Section 6.8 – OU6
- Section 6.9 – OU8

Section 6.10 presents an evaluation of LA concentrations in "background" soil and summarizes potential exposures and risks associated with disturbances of background soil. Section 6.11 summarizes the overall conclusions regarding potential risks from exposures to LA during soil disturbances.

Each of the following sections discuss the exposure populations of interest and present the selected RME and CTE exposure parameters values and calculated TWFs for each exposure scenario. Each section identifies the basis of the selected exposure parameters and notes if any Site-specific adjustments were applied. It is important to note that the exposure parameters and resulting TWFs are selected for the purposes of evaluating potential risks from each individual exposure scenario (i.e., the cumulative assessment may utilize different TWFs).

6.1 Residential and Commercial Properties in OU4 and OU7

6.1.1 Exposure Populations and Parameters

There are several populations who may be exposed to LA in air during outdoor soil disturbances at residential and commercial properties in OU4 and OU7. The primary receptor population of interest is residents. Because residential exposures may differ as a function of location within a property (i.e., the

amount of time in spent in yards is expected to be different than time spent in a garden), exposure parameters were specified separately for each of four exposure locations – yards, gardens/flowerbeds, driveways, and limited-use areas (LUAs). LUAs are portions of the property that are used on a more limited basis, such as pastures and mowed fields.

A second receptor population of interest is outdoor workers, such as local landscapers and lawncare maintenance workers. These individuals have the potential to perform soil disturbance activities on a more frequent basis than residents. As such, exposures to LA in air during outdoor soil disturbances at residential and commercial properties in OU4 and OU7 were evaluated separately for residents and outdoor workers.

For commercial properties, it is anticipated that exposures to LA in air during outdoor soil disturbances will be primarily associated with outdoor worker activities. However, because it is possible that future land use could transition from commercial to residential (and vice versa), commercial properties were not assessed separately from residential properties.

Table 6-1 (Panel A) presents the selected RME and CTE exposure parameters values and calculated TWFs for disturbances of surface soils at OU4/OU7 properties by exposure location.

6.1.2 Investigation Summary

The following subsections briefly summarize the outdoor ABS investigations that have been performed at residential and commercial properties in OU4 and OU7 to evaluate potential exposures to LA during soil disturbances in yards, gardens/flowerbeds, driveways, and LUAs.

6.1.2.1 Yards

There have been several different outdoor ABS investigations conducted in OU4 and OU7 to evaluate potential exposures to LA during disturbances of soils in yards. Although there have been some differences in the study designs from investigation to investigation, the basic study designs for yards have been generally similar. In general, the outdoor ABS studies of yards have evaluated three different soil disturbance activities – mowing, raking, and digging (see **Figure 2-2** for example photographs of these ABS activities). ABS activities were performed by EPA or DEQ contractors in accordance with specified ABS "scripts". The ABS script specifies how the sampling team conducts the ABS activity (i.e., what disturbance activities to perform, where they should be performed, how to conduct the activity, and for how long each activity should be performed). ABS air samples were collected using personal air monitors (i.e., the air sampling cassette was worn by the individual performing the disturbance activity). Unless specified otherwise below, co-located 30-point soil composite samples were collected for each ABS area at the time of the ABS activity to provide data on the LA concentrations in the soil being disturbed. In addition, estimates of visible vermiculite (VV) were determined at the time of the soil sampling. Yards selected for outdoor ABS evaluation included a range of soil LA concentrations, and included both yards where soil removals had and had not been performed.

There have been four different yard ABS investigations conducted in OU4 and one yard ABS investigation in OU7. Each of these studies is described briefly below.

In the summer of 2005, outdoor ABS was conducted during disturbances of yard soils as part of the *OU4 Supplemental RI Quality Assurance and Project Plan* (referred to as the SQAPP) (EPA 2005b). Outdoor ABS samples were collected during digging, raking, and mowing. A total of 18 ABS areas were selected to represent yards with soil LA concentrations ranging from non-detect to greater than 1%.

Co-located soil composite samples were collected at the time of the ABS; however, the sample sampling methodology employed at the time differed from current sampling protocols in that the sample was usually only a 4-point or 10-point composite (current protocol is to collect 30-point composites). Detailed results of the OU4 SQAPP outdoor ABS investigation are summarized in EPA (2007a). Because the SQAPP soil collection methodology differed from current protocols and subsequent outdoor ABS programs, outdoor ABS data from the SQAPP were not included in this risk assessment.

The largest outdoor ABS program in OU4 occurred from 2007-2008 (EPA 2007d). This sampling investigation performed outdoor ABS during disturbances of yard soils at 75 properties. Similar to the SQAPP investigation, outdoor ABS samples were collected during digging (simulating a child playing in an area of bare dirt with a bucket and shovel), raking, and mowing. Two rounds of outdoor ABS were conducted at each ABS area to span a range of soil moisture and meteorological conditions. The first sampling event was performed in the summer of 2007 (July to August) and the second sampling event was performed in the spring of 2008 (April to June). During each ABS sampling event, soil disturbance activities were performed over a 6-hour time interval, divided into three sub-periods of two hours each (one for each disturbance scenario). One ABS air sample was collected for each disturbance scenario for each sampling event. Detailed results of the 2007-2008 OU4 outdoor ABS investigation are summarized in EPA (2010d). In addition, CDM Smith (2013c, d) summarizes the results of a subsequent soil re-analysis effort for this investigation.

In 2010, EPA conducted another outdoor ABS investigation during yard soil disturbances in OU4 (CDM Smith 2010b). Unlike previous investigations, the digging scenario was modified to simulate a sprinkler maintenance activity (i.e., digging a hole using a long shovel and trowel). The mowing and raking scenarios were performed on a yard-wide basis, to reduce the amount of localized stress in one area that occurred during the 2007-2008 ABS study, and the ABS duration was reduced to one hour (20 minutes per disturbance scenario). In addition, unlike the previous investigations, a single ABS air sample was collected during each sampling event, representing a composite across all three soil disturbance scenarios (mowing, raking, and digging). A total of ten properties were selected for evaluation; three sampling events were conducted at each property in the summer of 2010, with events spaced about one month apart. ABS air samples were originally analyzed in 2010; a subset of the samples underwent a supplemental TEM analysis to improve the achieved analytical sensitivity in 2013. Detailed results of the 2010 OU4 outdoor ABS investigation (including the supplemental analyses) are summarized in CDM Smith (2014a).

In 2011, EPA conducted several residential ABS studies in OU4 to evaluate potential exposures from the disturbance of yard soils. These residential ABS investigations consisted of three different yard sampling scenarios. The specific objectives and study designs of each sampling scenario are described in the governing SAP, *2011 Residential Activity-Based Sampling SAP* (CDM Smith 2011b). In brief, the first scenario evaluated potential differences in ABS LA air concentrations as a function of the raking, mowing, and digging disturbance intensity (see Section 6.1.4.1.1 for a detailed discussion of differences in ABS script intensity), the second scenario evaluated potential differences in measured ABS LA air concentrations at a given property across sampling years, and the third scenario evaluated potential differences in measured ABS LA air concentrations during mowing activities pre- and post-irrigation. Multiple sampling events were conducted at each selected property in the summer of 2011. Detailed results of the 2011 OU4 outdoor ABS investigation are summarized in CDM Smith (2014b).

For OU7, DEQ conducted an outdoor ABS investigation during yard soil disturbances in 2011 (Tetra Tech 2011). This ABS study was conducted using an ABS script equivalent to the raking, mowing,

digging script used in the 2010 OU4 outdoor ABS investigation (see above). A total of 20 properties were selected for evaluation; ten properties to represent yards where a soil removal had been completed and ten properties to represent yards where no soil removal was deemed necessary (based on a property assessment and removal status at the time of the ABS). Two sampling events were conducted at each property, one in the spring and one in the summer of 2011. Detailed results of the OU7 outdoor ABS investigation are summarized in Tetra Tech (2013).

6.1.2.2 Gardens and Flowerbeds

There have been two outdoor ABS investigations conducted in OU4 gardens and flowerbeds and one outdoor ABS investigation in OU7 gardens. Each of these studies is described briefly below.

In 2001, a small-scale outdoor ABS study was performed at one residential property in OU4 to evaluate potential exposures when garden soil was actively disturbed by rototilling. This scenario was chosen both because vermiculite is known to have been added to a number of gardens in Libby, and because rototilling is a realistic and aggressive garden soil-disturbance scenario. A single garden, where previously collected soil samples showed trace levels of LA, was selected for evaluation. Two personal air monitoring samples were collected while rototilling the garden soil – one for the individual performing the rototilling and one for the rototiller assistant. Results of the rototilling ABS are summarized in EPA (2005b).

A larger outdoor ABS investigation of potential exposures during soil disturbances in gardens and flowerbeds OU4 was conducted in the summer of 2010 (CDM Smith 2010b). As part of this investigation, ABS was performed to simulate an adult gardening (i.e., digging in the soil with trowel and hands) to disturb the soil to a depth of 12 inches at six discrete locations distributed across the garden. A total of 20 residential properties were selected for evaluation; ten properties with VV noted in the garden/flowerbed (i.e., a soil removal was deemed necessary but had not yet been performed at the time of the ABS) and ten properties where no VV was observed (i.e., no soil removal was deemed necessary). Three sampling events were conducted at each property in the summer of 2010, with events spaced about one month apart. For each sampling event, a composite soil sample was collected to be representative of the entire garden/flowerbed ABS area. ABS air samples were originally analyzed in 2010; a subset of the samples underwent a supplemental TEM analysis to improve the achieved analytical sensitivity in 2013. Detailed results of the 2010 OU4 garden/flowerbed ABS investigation (including the supplemental analyses) are summarized in CDM Smith (2014a).

For OU7, an outdoor ABS investigation of potential exposures during soil disturbances in gardens was conducted in 2011 (Tetra Tech 2011). As part of this investigation, a composite ABS sample was collected that was representative of an adult gardening (i.e., digging in the soil with trowel and hands) at nine discrete locations distributed across the garden and performing rototilling of the entire garden. A total of 20 residential properties were selected evaluation; ten properties where a garden removal had been completed and ten properties where a garden removal was not deemed necessary (based on a property assessment). Two sampling events were conducted at each property, one in the spring and one in the summer of 2011. For each sampling event, a composite soil sample was collected to be representative of the entire garden. Detailed results of the OU7 garden ABS investigation are summarized in Tetra Tech (2013).

6.1.2.3 Driveways

Two outdoor ABS investigations have been performed to evaluate potential exposures to LA during disturbances of unpaved driveways, one investigation was performed in OU4 in 2010 (CDM Smith 2010b) and one investigation was performed in OU7 in 2012 (Tetra Tech 2011). In both

investigations, an (adult) EPA or DEQ contractor simulated a child playing on an unpaved driveway; the playing activities included both digging and biking activities. The child digging activity was conducted with the contractor sitting on the ground while digging or scraping the top surface of the driveway, pushing soil/rock to the side, and then replacing it at six discrete locations evenly distributed across the entire driveway. For the child biking activity, the contractor rode a small non-motorized tricycle with minimal ground clearance across the driveway in straight lines covering the entire area of the driveway (see **Figure 2-2** for an example photograph of this ABS activity).

For the OU4 investigation, a total of 20 residential properties were selected for evaluation; ten properties with VV noted in the driveway (i.e., a soil removal was deemed necessary, but had not yet been performed at the time of the ABS) and ten properties where no VV was observed (i.e., no soil removal was deemed necessary). Three sampling events were conducted at each property in the summer of 2010, with events spaced about one month apart. For each sampling event, a composite soil sample was collected to be representative of the entire driveway. Detailed results of the 2010 OU4 driveway ABS investigation are summarized in CDM Smith (2014a).

For the OU7 investigation, a total of 20 residential properties were selected evaluation; ten properties where a driveway removal had been completed and ten properties where a driveway removal was not deemed necessary (based on a property assessment). Two sampling events were conducted at each property, one in the spring and one in the summer of 2011. For each sampling event, a composite soil sample was collected to be representative of the entire driveway. Detailed results of the OU7 driveway ABS investigation are summarized in Tetra Tech (2013).

6.1.2.4 Limited-Use Areas

As described above, most outdoor ABS efforts conducted at properties in OU4 and OU7 have focused on common-use areas (CUAs), such as the yard, and specific-use areas (SUAs), such as gardens, flowerbeds, and driveways. However, outdoor ABS studies have also been conducted in portions of the property that are used on a more limited basis (i.e., LUAs). In the summer of 2011, an outdoor ABS investigation was performed in OU4 to evaluate potential exposures to LA during soil disturbances in LUAs (CDM Smith 2012b).

Several types of soil-disturbance activities could be performed in LUAs, such as mowing, haying (i.e., cutting/bailing hay), horseback riding, and ATV riding. For the purposes of the LUA outdoor ABS investigation, ATV riding was selected for evaluation because this exposure scenario is likely to occur on a more frequent basis than other activities, is likely to generate more airborne dust, and is an activity that likely applies to more individuals in the community than other exposure scenarios.

A total of ten LUAs were selected for evaluation from seven residential properties in OU4, spanning a range of LA concentrations in soil (non-detect and trace). A total of three sampling events were performed at each LUA in the summer of 2011. During each sampling event, two EPA contractors rode an ATV across the LUA for one hour (see **Figure 2-2** for an example photograph of this ABS activity). For the first 30 minutes, riders engaged in activities that were representative of riding in a single-file line (i.e., one rider leading, one rider following), with the leader/follower switching positions after 15 minutes. For the last 30 minutes, riders rode separately and covered as much of the LUA as possible. During each sampling event, a soil sample was collected to be representative of the entire LUA. Detailed results of the OU4 LUA ABS investigation are summarized in CDM Smith (2014b).

6.1.3 Role of Soil Data in Evaluating Risks

There are more than 5,000 residential/commercial properties in OU4 and more than 1,000 residential/commercial properties in OU7. To date, EPA and DEQ have performed outdoor ABS at about 200 properties in OU4 and OU7. Because it is not feasible to evaluate risks by conducting outdoor ABS at every property, it is necessary to use the measured ABS data from the properties where ABS has been performed to draw risk conclusions about properties where ABS has not been performed. For outdoor ABS associated with disturbances of soil (e.g., residential disturbances of yard soil), this is accomplished by assuming that LA concentrations in ABS air will be similar for locations with similar levels of LA in soil and similar disturbance activities. An inherent assumption of this approach is that the many random variables that influence release of LA from yard soil to air will tend to average out over time, and that it is soil LA concentration alone that is the key determinant of the long-term average concentration in outdoor ABS air.

Soil samples collected at the Site are analyzed for LA using polarized light microscopy (PLM). Prior to analysis, each soil sample is dried and sieved through a ¼-inch screen. Particles retained on the screen (if any) are referred to as the coarse fraction. Particles passing through the screen are referred to as the fine fraction, and this fraction is ground by passing it through a plate grinder. The resulting material is referred to as the fine ground fraction. The coarse fraction (if any) is examined using stereomicroscopy, and any particles of asbestos (as confirmed by PLM) are removed and weighed to provide a mass fraction of the LA content in accordance with Site-specific SOP SRC-LIBBY-01 (referred to as PLM-Grav). Only a limited number of soils collected as part of the outdoor ABS sampling programs had a coarse fraction; and most of these coarse fractions were reported as non-detect for LA when analyzed by PLM-Grav. Because of this, soil results utilized in the risk assessment focus only on the PLM results for the fine ground fraction.

An aliquot of the fine ground fraction is analyzed using the Site-specific visual area estimation PLM method, as detailed in SOP SRC-LIBBY-03 (referred to as PLM-VE). PLM-VE is a semi-quantitative method that utilizes Site-specific LA reference materials to allow assignment of fine ground samples into one of four concentration “bins”, as follows:

- *Bin A (ND):* non-detect
- *Bin B1 (Trace):* detected at levels lower than the 0.2% (by mass) LA reference material
- *Bin B2 (<1%):* detected at levels lower than the 1% (by mass) LA reference material but greater than or equal to the 0.2% LA reference material
- *Bin C:* LA detected at levels greater than or equal to the 1% LA reference material; estimated soil concentrations are reported to the nearest whole percent

As noted above, for the 2007-2008 yard ABS investigation (see Section 6.1.2.1), a subset of the collected soil samples were subsequently reanalyzed by PLM-VE by a different analytical laboratory (CDM Smith 2013c, d). The higher of the two reported laboratory results is used to represent the LA soil concentration for these samples. In addition, as part of the general quality control (QC) program for the Site, some soil samples are randomly selected for reanalysis (e.g., preparation duplicates, laboratory duplicates, inter-laboratory analyses). In cases where multiple analyses are available for a soil sample, the highest result is used to represent the soil concentration.

6.1.4 Calculation of EPCs

6.1.4.1 Yards

6.1.4.1.1 Accounting for Differences in Yard ABS Script Intensity

The outdoor ABS studies conducted for OU4 yards have utilized ABS scripts with varying intensities of soil disturbance. The 2007-2008 OU4 outdoor ABS investigation (see Section 6.1.2.1) utilized ABS scripts that are ranked as “high intensity” scripts. Under the “high intensity” yard script, mowing, raking, and digging disturbance activities were performed on a sub-area of the yard for approximately two hours per activity (i.e., two hours raking, two hours mowing, two hours digging). Often, this resulted in the sub-area being mowed/raked multiple times over the course of the sampling activity duration. As a result, grass was typically worn down and bare patches of soil were often observed by the end of the sampling period, which may have resulted in elevated LA releases during sampling.

The 2010 and 2011 OU4 outdoor ABS investigations and the OU7 outdoor ABS investigation (see Section 6.1.2.1) mainly[10] utilized ABS scripts that are ranked as “typical intensity” scripts. Under the “typical intensity” yard script, ABS was conducted on a yard-wide basis, the sampling duration per disturbance scenario was reduced (i.e., 20 minutes versus two hours per scenario), and the mowing/raking activities were more representative of expected behaviors (i.e., one pass over the yard), thus reducing the amount of localized stress in one area.

Because it is expected that individuals at a property may disturb soil under different intensities over time, use of only the high intensity ABS results, may tend to bias long-term exposure estimates high. Likewise, use of only the typical intensity ABS results, may tend to bias long-term exposure estimates low. Thus, to account for differences in disturbance intensity in long-term exposure estimates, the risk calculations utilized both types of ABS results, but weighted exposures based on the script intensity as follows:

$$Risk = (EPC_{high} \cdot TWF_{high} \cdot IUR_{LA}) + (EPC_{typical} \cdot TWF_{typical} \cdot IUR_{LA})$$

$$HQ = (EPC_{high} \cdot TWF_{high} / RfC_{LA}) + (EPC_{typical} \cdot TWF_{typical} / RfC_{LA})$$

where:

EPC_{high} = Exposure point concentration, outdoor ABS during yard disturbances under high intensity ABS script (PCME LA s/cc)

$EPC_{typical}$ = Exposure point concentration, outdoor ABS during yard disturbances under typical intensity ABS script (PCME LA s/cc)

TWF_{high} = Time-weighting factor for yard soil disturbances under high intensity disturbance activities (unitless)

$TWF_{typical}$ = Time-weighting factor for yard soil disturbances under typical intensity disturbance activities (unitless)

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[10] Scenario 1 of the 2011 outdoor ABS program included sample collection during both “high intensity” and “typical intensity”.

For the purposes of this risk assessment, it was assumed that 5% of the total yard disturbance time is spent performing high intensity disturbance activities:

$$TWF_{high} = TWF_{total} \cdot 0.05$$

$$TWF_{typical} = TWF_{total} \cdot 0.95$$

The uncertainty assessment (see Section 10.1.6) provides additional information on how risk estimates would change if the time spent performing high intensity disturbance activities were higher than assumed.

6.1.4.1.2 Accounting for Differences in Yard ABS Activities

ABS scripts for the evaluation of yard soil disturbances have typically included three different disturbance activities – raking, mowing, and digging. These three activities are considered realistic examples of soil disturbance activities that may occur in yards. For outdoor exposures during soil disturbance activities, the EPC was calculated as the average ABS air concentration, combining across activities (mowing, raking, digging) and across time (spring and summer). This is because the goal is to estimate the long-term average concentrations over many years of various types of outdoor yard soil disturbance activities.

6.1.4.1.3 Stratification by Soil Concentration

As noted above, because it is not feasible to perform outdoor ABS at every property, it is necessary to use data on LA in soil to extrapolate to properties without ABS. In this regard, EPCs were calculated by grouping the outdoor ABS air samples using the co-located yard soil LA concentration, as determined based on the results of the PLM-VE analysis.

Table 6-2 (Panel A) presents the calculated EPCs associated with disturbances of yard soil at properties in OU4 and OU7. As seen, the majority of outdoor ABS air samples during yard soil disturbances have been collected from properties where the soil concentration is Bin A or Bin B1. Although the 2010 ABS program sought to identify and evaluate properties with higher soil concentrations, because soil removal efforts have targeted properties with higher soil concentrations, there are limited or no data for Bin B2 and Bin C soil concentrations under the typical intensity ABS script. Therefore, for the purposes of the risk assessment, these two soil concentration bins were combined (Bin B2/C).

6.1.4.2 Gardens

For gardens, two different types of soil disturbance activities have been performed – an aggressive ABS scenario (rototilling) and a more typical activity scenario (digging with a trowel or shovel). Because potential LA releases are likely to be much higher during rototilling, and because rototilling is an activity that is likely to occur less frequently than typical gardening activities, when possible, EPCs for these two garden ABS scenarios were calculated separately.

Because it is necessary to extrapolate the garden ABS results to properties without ABS, EPCs were calculated by grouping the outdoor ABS air samples using the co-located garden soil LA concentration. The same soil concentration categories described for yards (see Section 6.1.4.1.3) are used for gardens. **Table 6-2** (Panel B) presents the calculated EPCs associated with disturbances of garden soil at properties in OU4 and OU7.

6.1.4.3 Driveways and Limited-Use Areas

For driveways and LUAs, the ABS scripts did not differ from investigation to investigation; thus, there was no need to stratify EPCs by script activity or intensity. However, it was necessary to calculate EPCs separately for each LA soil concentration bin to extrapolate ABS results to properties where ABS activities have not been performed. The same soil concentration categories described for yards (see Section 6.1.3.1.3) were used for driveways and LUAs. **Table 6-2** presents the calculated EPCs associated with disturbances of driveway soil (Panel C) and LUA soil (Panel D) at properties in OU4 and OU7.

6.1.5 Risk Estimates

6.1.5.1 Yards

Table 6-3 presents estimated cancer risks and non-cancer HQs from exposures to LA during soil disturbances at residential and commercial properties in OU4 and OU7. **Table 6-3a** presents risks for residential exposures and **Table 6-3b** presents risks for outdoor worker exposures. For both tables, Panel A presents risks based on RME and Panel B presents risks based on CTE.

<u>OU4</u>

For residential exposures (**Table 6-3a**) to LA during yard soil disturbances in OU4, although estimated RME cancer risks are below 1E-04 for all soil concentration categories, RME non-cancer HQs are above 1 when LA is detected in yard soils (i.e., both for Bin B1 and Bin B2/C soil concentrations). High intensity and typical intensity disturbances each account for approximately half of the total HQ. The RME HQ is below 1 based on Bin A soil concentrations (non-detect for LA). Estimated CTE cancer risks are below 1E-04 and non-cancer HQs are below 1 for all soil concentration categories.

For outdoor worker exposures (**Table 6-3b**) to LA during yard soil disturbances in OU4, RME and CTE cancer risks are at or below 1E-04, but RME non-cancer HQs are above 1 when LA is detected in yard soils. The CTE HQ is also above 1 for Bin B2/C soil concentrations. The estimated RME and CTE non-cancer HQs are below 1 based on Bin A soil concentrations.

It is important to note that an HQ above 1 does not necessarily mean that adverse non-cancer effects will occur. As noted previously, there is a margin of safety built into the RfC through the application of an UF (EPA 2014d). However, the probability of an adverse effect tends increase as the HQ increases. The contribution of OU4 yard soil disturbance exposure scenarios to cumulative risk is discussed in Section 9.

<u>OU7</u>

For OU7, estimated RME and CTE cancer risks are below 1E-04 and non-cancer HQs are less than 1 for exposures to LA during yard soil disturbances for both receptors. However, the OU7 ABS data have two important limitations. First, the ABS activities performed are only representative of typical intensity disturbances, no data were collected under high intensity disturbances. As shown for OU4, high intensity disturbances account for approximately half of the total HQ. Thus, OU7 risk estimates are likely biased low. Second, nearly all of the ABS data were collected in yards where no LA was detected (Bin A); only one ABS air sample was collected from a yard with Bin B1 (trace) soil concentrations and no samples were collected in yards with Bin B2/C soil concentrations (see **Table 6-2**). Therefore, these data may not be representative of potential exposures and risks when LA is

detected in yard soil. In this regard, the risk estimates from OU4 can be used to infer potential risks for properties in OU7.

6.1.5.2 Gardens, Driveways, Limited-Use Areas

For residential exposures (**Table 6-3a**), estimated RME and CTE cancer risks are below 1E-04 and non-cancer HQs are below 1 during soil disturbances in gardens, driveways, and LUAs for all soil concentration categories. For outdoor worker exposures (**Table 6-3b**), with the exception of the garden rototilling scenario, estimated RME and CTE cancer risks are below 1E-04 and non-cancer HQs are below 1 for all soil concentration categories. Outdoor worker exposures while rototilling in gardens with trace (Bin B1) concentrations of LA resulted in an estimated RME non-cancer HQ of 4; both the RME and CTE cancer risks were below 1E-04 and CTE HQ was below 1. The contribution of garden, driveway, and LUA soil disturbance exposure scenarios to cumulative risk is discussed in Section 9.

However, the majority of ABS air samples collected from gardens, driveways, and LUAs are representative of soil concentrations with lower levels of LA (Bin A or Bin B1). It is expected that exposures and risks would be higher when soil concentrations are Bin B2/C, but the available data are too limited to provide reliable information on the magnitude of the potential increase in exposure.

6.1.6 Extrapolation to Properties Without ABS

6.1.6.1 Determining Exposure Area-wide Risk Estimates

In interpreting these risk estimates, it is important to understand that these calculations are intended to represent a given LA soil concentration. However, a specified exposure area for a property may have varying LA soil concentrations, ranging from Bin A to Bin C by PLM-VE, with differing spatial extents. As discussed in Section 2.3.3, the evaluation of risk is based on the average exposure across the entire exposure area. Thus, for exposure areas that encompass varying LA soil concentrations, it is necessary to derive a spatially-weighted average risk estimate for the entire exposure area. **Figure 6-1** presents a simplified example of this approach. As shown in this example, soil concentration information is available from three subareas within the exposure area (Panel A). These soil concentration data are translated into a corresponding non-cancer HQ value (based on the OU4 yard soil residential RME HQ estimates presented in **Table 6-3a**) – i.e., the Bin A soil concentration is assigned an HQ value of 0.1, the Bin B1 soil concentration is assigned an HQ value of 2, and the Bin C concentration is assigned an HQ value of 6 (Panel B). Therefore, in this example, exposure area-wide average HQ is calculated by weighting each area appropriately (based on its spatial contribution to the total exposure area), yielding an exposure area-wide HQ of 2 (Panel C). This same approach can be used to derive exposure area-wide estimates of cancer risk.

6.1.6.2 Overview of Soil Concentrations Remaining at Properties

Since 2000, EPA has completed exterior soil removals at more than 1,600 properties in OU4 and 40 properties in OU7 as part of the emergency response removals. Soil removal efforts have sought to address "worst first", meaning that properties with the highest levels of contamination were prioritized first for removal. The "triggers" that have been used to determine the need for soil removal differ by use area (i.e., triggers for yards differ from the triggers for gardens) and have changed over time. A summary of the soil removal triggers is provided in the *Libby Asbestos Site Residential/Commercial Cleanup Action Level and Clearance Criteria Technical Memorandum* (EPA 2003) and two subsequent memorandum amendments (*Amendment A* – CDM Smith 2011c; *Amendment B* – CDM Smith 2014c).

In general, at the time of this risk assessment, properties in OU4 and OU7 can be classified into four basic categories:

1. Properties where soil removals have already been completed.
2. Properties where soil removal has not been deemed necessary based on an evaluation of property-specific conditions relative to the current soil removal triggers.
3. Properties where soil removal is deemed necessary, but has not been performed (this includes properties that are currently in the removal queue and properties where the owner has refused or deferred removal efforts).
4. Properties where no soil information is available (e.g., owner has refused property access and no evaluation of property-specific conditions has been performed).

Prior to 2014, the primary soil removal triggers were the presence of VV in SUAs, such as gardens, flowerbeds, and driveways, and/or LA levels ≥1% (Bin C) in CUAs, such as yards. Once EPA removal contractors were at a property, soil removal efforts would consist of excavating all soils in these areas with detected LA (i.e., Bin B1, Bin B2, and Bin C conditions would be removed and replaced with topsoil fill materials) up to a depth of about 12-18 inches.

Table 6-4 summarizes the expected surface soil concentrations at properties in OU4 and OU7 where soil removals have and have not been completed. As shown, for properties where a soil removal has been completed (Category #1), surface soils that remain "post-removal" should be[11] a mixture of Bin A (non-detect for LA) and topsoil fill materials (which are also non-detect for LA). As shown in **Table 6-3**, LA exposures due to disturbances of Bin A soils in yards, gardens, flowerbeds, and driveways yield estimated RME cancer risks below 1E-04 and non-cancer HQs below 1.

For properties where no soil removal had been deemed necessary prior to 2014 (Category #2), soil concentrations could be as high as Bin B2 across the total exposure area (Bin C concentrations would have triggered a soil removal). As discussed above, properties where yard soil concentrations are Bin B1 or Bin B2 have the potential to result in RME non-cancer HQs greater than 1 (see **Table 6-3**), depending upon their spatial extent. Therefore, there may be properties in OU4 and OU7 where soil removal actions have not yet been completed that have the potential to result in elevated LA exposures if soils are disturbed. Beginning in 2014, the soil removal triggers were modified to conduct soil removals at properties with Bin B1 (depending upon their spatial extent) and Bin B2 (regardless of spatial extent) soil concentrations. Specifics on these modified soil triggers are presented in *Amendment B* (CDM Smith 2014c). Bin B1 (trace) surface soils are allowed to remain in place in SUAs and CUAs, provided that their spatial extent is less than 25% of the total exposure area. This decision was based on the finding that, if 75% or more of the total exposures area is Bin A and the remainder is Bin B1, the estimated area-wide RME non-cancer HQ (see Section 6.1.6.1) will not exceed 1.

For properties where soil removal is deemed necessary, but has not been performed (Category #3), the potential exposures and risks from soil disturbance activities will depend upon the nature and extent of the LA concentrations in soil present at the property. However, it is possible that Bin C concentrations may be present. As illustrated in **Figure 6-1**, properties where yard soil concentrations

[11] On occasion, subsequent soil sampling efforts at "post-removal" properties have identified LA detections.

are Bin C have the potential to result in area-wide RME non-cancer HQs greater than 1, even if their spatial extent is small.

For properties where no soil information is available (Category #4), potential exposures and risks from soil disturbance activities cannot be determined.

6.1.6.3 Uncertainties in Extrapolating Using Soil Data

There are several challenges in extrapolating ABS results to properties without ABS using soil data, especially when using historical soil data.

First, soil sampling methodologies have changed over time. As noted above, most of the soil samples collected as part of outdoor ABS investigations are 30-point composite samples, which encompass the extent of the ABS area. Prior to 2007, soil samples collected at the Site were usually collected as five-point composite samples. Thus, there is expected to be more variability in these historical soil samples relative to the 30-point composites. In addition, the number of soil samples collected at each property varied, depending upon the types of use areas identified (e.g., yards, driveways) and the size of the use area, and sampling efforts tended to focus on more frequently used areas. Any extrapolation of ABS results based on historical soil samples should consider these data limitations.

Second, unlike traditional chemistry methods, where analytical results are based on the output of a laboratory instrument, the PLM-VE method is inherently subjective. In this method, the PLM analyst utilizes visual estimation techniques (e.g., standard area projections, photographs, drawings, or trained experience) to estimate the asbestos content of the soil. Results are reported semi-quantitatively for levels below 1%, based on visual comparisons to LA-specific reference materials. Results of inter-laboratory assessments for the PLM-VE method show that there are differences between the analytical laboratories in results reporting (CB&I Federal Services, LLC [CB&I] 2012, 2014; CDM Smith 2012c, 2014d). In particular, EPA's Environmental Services Assistance Team, Region 8 (ESATR8) laboratory has demonstrated proficiency in detecting the presence of "trace" levels of LA (Bin B1) in soil compared to other (non-ESATR8) PLM laboratories (CDM Smith 2014d). Because the majority of the soil samples that were used to group the ABS air data into soil concentration categories were analyzed by the ESATR8 laboratory, it may not be appropriate to extrapolate ABS results based on soil concentrations estimated by non-ESATR8 laboratories.

In summary, extrapolation of outdoor ABS data to properties without ABS using soil data is most appropriate when the soil samples have been collected using a 30-point composite sampling methodology and when PLM-VE results are based on analyses performed by the ESATR8 laboratory. Uncertainties associated with between-laboratory variability and changes in soil sampling methodology are discussed further in Sections 10.1.4 and 10.1.5, respectively.

6.1.7 Risks from Contaminated Subsurface Soil

As noted above, during soil removal efforts conducted at properties in OU4 and OU7, soils with detected LA are removed and replaced with topsoil fill materials. However, at some properties, contamination was still present at the maximum soil removal excavation depth[12]. In the event that digging occurs in areas where subsurface soil contamination was left in place at depths greater than the extent of the topsoil fill material, such as a resident digging a deep hole to plant a tree or an outdoor worker digging a new sewer line, it is possible that individuals may be exposed to LA-

[12] In cases where 1% or greater was left behind, the excavation depth was increased to 36 inches (i.e., there should be about 3 feet of topsoil fill material covering the subsurface contamination).

contaminated subsurface soils. It is expected that these exposures would occur less frequently than exposures to surface soils, but may have the potential to result in higher exposures because the subsurface materials being disturbed could have higher LA concentrations.

Table 6-1 (Panel B) presents the selected RME and CTE exposure parameters values and calculated TWFs for disturbances of subsurface soils at OU4/OU7 properties. For the resident, it is assumed that all subsurface soil exposures occur at their residence. However, for the outdoor worker it is likely that they may be exposed to subsurface soils across multiple residential/commercial properties with varying levels of subsurface contamination. For the purposes of these risk calculations, it is assumed that 65% of their subsurface soil exposure is to Bin A (non-detect) concentrations, 15% of their subsurface exposure is to Bin B1 (trace) concentrations, and 20% of their subsurface exposure is to Bin B2/C concentrations. This is based on the observation that, of the more than 1,600 properties in OU4 where an outdoor soil removal effort has been completed, the confirmation soil samples (taken from the bottom of the excavation area) showed about 65% were non-detect for LA, about 34% had LA concentrations reported as <1%[13] at the bottom of the excavation area, and less than 2% had LA concentrations of 1% or greater at the bottom of the excavation area (EPA 2014a).

There are no ABS air data that are specific to subsurface soil disturbance scenarios in OU4/OU7. However, a subset of the ABS air samples from the yard soil disturbance activities (see Section 6.1.2.1) included a digging disturbance scenario (simulating a child playing in an area of bare dirt). While it is expected that this type of digging scenario is likely to be biased high, as it is representative of a high intensity disturbance condition, it is used in these calculations to provide screening level risk estimates for potential exposures from disturbances of subsurface soil for each soil concentration category (i.e., Bin A, Bin B1, Bin B2/C).

Table 6-5 presents estimated cancer risks and non-cancer HQs from exposures to LA during subsurface soil disturbances at residential and commercial properties in OU4 and OU7. Panel A presents risks based on RME and Panel B presents risks based on CTE. As shown, when this exposure scenario is considered alone, estimated RME cancer risks are below 1E-04 and non-cancer HQs are below 1 during subsurface soil disturbances for all soil concentration categories for residents. However, for the outdoor worker, RME cancer risks approach 1E-04 and non-cancer HQs are above 1, primarily due to digging in areas where concentrations are Bin B2/C. These results show that this exposure scenario alone has the potential to approach or exceed EPA's acceptable risk limits. However, it is important to recall that these are screening level estimates that have the potential to be biased high. The contribution of subsurface soil disturbance exposure scenarios to cumulative risk is discussed in Section 9.

Note that these subsurface soil risk estimates apply only to exposures during the digging activity itself. If contaminated subsurface soils that are unearthed during these digging activities are not managed properly and surface soils become re-contaminated as a result, it is possible that significant exposures and risks could result, depending upon the type of subsurface contamination encountered and the spatial extent that it is spread at the surface (see **Table 6-3**).

[13] Confirmation soil samples are analyzed by PLM using NIOSH 9002, which does not stratify concentrations below 1% into Bin B1 or Bin B2, simply reporting results as "<1%". It is assumed that half of all results reported by NIOSH 9002 as <1% would have been ranked as Bin B1 and half as Bin B2.

6.2 Schools and Parks in OU4 and OU7

6.2.1 Exposure Populations and Parameters

For schools, the receptor populations of interest for evaluating exposures during soil disturbances include students and outdoor maintenance workers. Because the student population differs by the type of school (i.e., younger children attend elementary school, older children attend high school), student exposure parameters were determined separately by school. Because different worker maintenance activities are likely performed at different frequencies for different schools, exposures were evaluated separately by school for mowing/edging school lawns, power-sweeping sidewalks, and general maintenance activities on school grounds (e.g., digging and raking).

For parks, the primary receptor population of interest is recreational visitors. The type of recreational visitor evaluated (children, adults) depends upon the anticipated park use. For example, playgrounds were assumed to be used primarily by younger children, whereas the ball fields and golf courses were assumed to be primarily used by older children and adults. For golf courses, exposures were also evaluated for outdoor workers that perform course maintenance activities, such as mowing, aerating turf, and raking bunkers.

Table 6-6 presents the selected exposure parameters values and calculated TWFs for disturbances of soils at schools and parks in OU4 and OU7. For OU4 schools, the exposure parameters are based on information provided by school administrators. Because the basis (RME/CTE) of the exposure parameters provided by school administrators was not specified and because there is not likely to be substantial variability in the student exposures for a given school, only one set of exposure parameters were determined (i.e., RME and CTE values were not selected).

In reviewing these exposure parameters, it is acknowledged that several of the exposure durations are less than 10 years (e.g., childhood exposures at daycare, high school sporting activities). Typically, these types of shorter exposure duration scenarios are not evaluated individually because the exposure duration is less than the basis of the toxicity values, which are intended to apply to a lifetime exposure scenario. However, this risk assessment calculates exposure and risk for all exposure scenarios, regardless of exposure duration, to demonstrate the pathway-specific contribution to lifetime exposures to inform decision-making.

6.2.2 Investigation Summary

In June and July 2005, outdoor ABS samples were collected at the Cabinet View Country Club Golf Course while course workers performed various maintenance activities (e.g., mowing, aeration, raking bunkers) on the course fairways, greens, and tees. A total of seven personal air monitoring samples were collected. Detailed results from the outdoor ABS at the golf course are presented in EPA (2007a).

In June 2008, outdoor ABS was performed at each of five school buildings in Libby (EPA 2009g). Outdoor activity scenarios for students and maintenance staff were selected based on interviews with school administrators. For students, this included playing sports (e.g., soccer, baseball) in designated sports areas, playing on playground equipment (e.g., swing sets), and walking/running over various ground materials (i.e., grass, sand). For outdoor maintenance workers, this included digging and raking on school grounds, manual sweeping of blacktop play areas and sidewalks, power sweeping parking lots, and mowing and edging school lawns (see **Figure 2-2** for example photographs of these ABS activities). At each school, the administrators identified outdoor areas that were most commonly used by students or maintenance staff for typical outdoor behaviors. In general, one to three distinct areas used for play or sports activities were selected at each school for conducting student scenarios,

while maintenance worker scenarios took place across the school grounds. The power sweeping scenario was performed in the parking lots at two schools (Libby Administration Building and Libby High School). Detailed results from the outdoor ABS at the OU4 schools are presented in (EPA 2010e). A subset of the outdoor ABS air samples underwent a supplemental TEM analysis to improve the achieved analytical sensitivity in 2010; these supplemental analyses were included in EPC calculations.

In 2011, DEQ conducted outdoor ABS to evaluate potential exposures during soil disturbance activities at playgrounds and ball fields at parks and schools in Troy (Tetra Tech 2011). At Morrison Elementary School and the Roosevelt Park playground, the types of ABS activities evaluated included playing on playground equipment, such as swing sets, merry-go-rounds, jungle-gyms, and see-saws, and digging in sand boxes. At the Roosevelt Park ball fields and the Timber Beast Disk Golf Course, ABS activities included playing baseball, football, soccer, and/or Frisbee® golf. **Figure 2-2** provides example photographs of these ABS activities. Two sampling events were conducted at each school/park, one in the spring and one in the summer of 2011. Detailed results from the outdoor ABS schools and parks in OU7 are presented in Tetra Tech (2013).

6.2.3 Calculation of EPCs

Table 6-7 presents summary statistics of the measured outdoor ABS air concentrations for each type of soil disturbance activity for each school, park, and golf course in OU4 and OU7. Because potential exposure durations and conditions differ by location, EPCs were calculated separately by location. A cumulative evaluation of potential exposures across multiple schools (e.g., exposure for a receptor that attends Libby schools beginning in elementary school through high school), is presented in Section 9.

6.2.4 Risk Estimates

Table 6-8 presents estimated cancer risks and non-cancer HQs from exposures to LA during soil disturbances at each school, park, and golf course in OU4 and OU7. These results indicate that, when these exposure scenarios are considered alone, estimated cancer risks are below 1E-05 and non-cancer HQs are at or below 0.1 for all exposure scenarios. The contribution of these exposure scenarios to cumulative risk is discussed in Section 9.

6.3 Trails/Bike Paths in OU4 and OU7

6.3.1 Exposure Populations and Parameters

Recreational visitors are the receptor population of interest for the purposes of evaluating potential exposures to LA while riding bicycles on trails, bike paths, and along roads in OU4 and OU7. Two scenarios were evaluated: riding a bike (assumed to be older children and adults) and riding in a trailer attached to a bike (young children). Because exposure concentrations could differ between riders and children in bicycle trailers, exposures were determined separately for each scenario.

Table 6-9 presents the selected RME and CTE exposure parameter values and calculated TWFs for disturbances of soils while bicycling in OU4 and OU7.

6.3.2 Investigation Summary

Two different ABS investigations have been conducted at the Site to evaluate potential exposures while riding bicycles on trails, bike paths, and along roads. In the summer of 2010, an investigation was performed by EPA to evaluate exposures in OU4 (CDM Smith 2010b). In the summer of 2011, an analogous investigation was performed by DEQ to evaluate exposures in OU7 (Tetra Tech 2011).

For both investigations, the biking activity was conducted with two EPA or DEQ contractors riding non-motorized, two-wheeled bicycles equipped for use on non-paved roads. In addition, a bicycle trailer, built to transport a 50-pound child, was affixed to the back of one (OU4) or both (OU7) of the bicycles for the entire event and an air monitor was mounted inside the trailer. Two types of ABS air samples were collected as part of this scenario – adult rider samples and trailer samples. The two riders traveled in single file along the path (which included both paved and unpaved trails, roads, and alleys), with the riders alternating positions (leading and trailing) throughout the sampling event, and the trailing riders trying to ride in the dust cloud of the rider in front (as much as was safe and practical) (see **Figure 2-2** for an example photograph of this ABS activity). During these events, the bicycle riders varied their speed between 3 and 15 miles per hour (mph), with a target average speed of 8 mph, adjusted as appropriate to meet path conditions.

For OU4, because it is expected that some riders will tend to favor the use of trails/paths in smaller subareas of Libby rather than riding at random across the entire city, the ABS investigation was conducted in three different sectors (see **Figure 6-2**). A total of ten one-hour sampling events were conducted in each of the three sectors. ABS air samples were originally analyzed in 2010; a subset of the samples underwent a supplemental TEM analysis to improve the achieved analytical sensitivity in 2013. Detailed results of the OU4 bicycling ABS investigation (including the supplemental analyses) are summarized in CDM Smith (2014a).

For OU7, a total of ten one-hour sampling events were conducted, with each sampling event performed across the entire town of Troy (see **Figure 6-3**). Results of the OU7 bicycling ABS investigation are summarized in Tetra Tech (2013).

6.3.3 Calculation of EPCs

Table 6-10 (Panel A) presents summary statistics for outdoor ABS air associated with disturbances of soil while riding bicycles in OU4 (stratified by sector) and OU7. As seen, all ABS air samples collected in OU4 were non-detect regardless of sector; therefore, risk estimates were not calculated separately by sector for OU4. Because the bicycle riding ABS scenarios were conducted in such a way that they are representative of the frequently used bike paths and trails in OU4 and OU7, there was no need to extrapolate ABS air results to un-sampled locations using soil data. Thus, it was not necessary to calculate EPCs stratified by soil concentration. However, because path conditions could differ between OU4 and OU7, EPCs were calculated separately for OU4 and OU7. EPCs were also calculated separately for each exposure location (i.e., rider and trailer).

6.3.4 Risk Estimates

Table 6-10 presents estimated cancer risks and non-cancer HQs from exposures to LA while bicycling on trails, bike paths, and along roads in OU4 and OU7 based on RME (Panel B) and CTE (Panel C). These results indicate that, when these exposure scenarios are considered alone, estimated RME and CTE risks are below 1E-06 and non-cancer HQs are well below 0.1 for all bicycling exposure scenarios. The contribution of these exposure scenarios to cumulative risk is discussed in Section 9.

6.4 Exposures in OU1

OU1 includes areas affected by contamination released from the former Export Plant. The former Export Plant is situated on the south side of the Kootenai River, just north of the downtown area of the City of Libby, Montana (see **Figure 1-5**). OU1 covers roughly 17 acres and is divided into three areas (Area 1, Area 2, and Area 3) (see **Figure 6-4**). Area 1, the former Export Plant area, has been converted to a landscaped park with paved access and parking, with the exception of an area used by

David S. Thompson Search and Rescue. Area 2, the former Riverside Park, has been combined with Area 1 to create the Riverfront Park serving a variety of recreational visitors. The main features of the park include two boat ramps, a pavilion with surrounding lawn areas and picnic tables. Area 3, the embankments, consists of undeveloped land owned and maintained by MDT. MDT currently performs only periodic maintenance of these embankments as needed (e.g., application of herbicides, replacement of guardrails, and maintenance of roadside light posts).

Numerous investigations and removal activities have occurred at OU1. Details of investigation and remediation activities conducted at the OU1 are provided in the *OU1 RI* (EPA 2009c), the *OU1 Record of Decision* (ROD) (EPA 2010a), and the *OU1 Remedial Action Report* (CDM Smith 2013e). Remedial actions at OU1 are complete and included removal (excavation and disposal) and containment (with soil covers) of asbestos-containing source materials. There are no areas within OU1 with LA-contaminated soils remaining at the surface. However, because buried residual vermiculite and contaminated subsurface soil remains at OU1, institutional controls (ICs) are in place which restrict subsurface disturbance activities (e.g., construction activities that involve soil excavation or earthwork) to mitigate potential future exposures from contamination left at depth.

6.4.1 Exposure Population and Parameters

There are two potential receptor populations that may be exposed to LA during soil disturbance activities at Riverfront Park in OU1 – recreational visitors and outdoor workers (park maintenance worker). While search and rescue volunteers/workers may use facilities in OU1, it is assumed that exposures will primarily occur inside the David S. Thompson Search and Rescue building (see Section 7.4 for an evaluation of indoor worker exposures).

Visitors to the park may engage in a variety of activities, such as picnicking in the pavilion and recreating on the lawn areas. However, risk estimates were calculated based on an outdoor worker scenario only, because this population is likely to have the highest exposure potential (i.e., the types of activities performed by park maintenance workers would tend to result in more frequent and higher intensity soil disturbances than the types of activities performed by recreational visitors). Different areas of the Riverfront Park require different types of lawn maintenance equipment. Because exposure conditions and exposure duration could differ depending upon the maintenance activity being performed, exposure parameters were determined separately for each of two activities – mowing and weed-trimming.

Table 6-11 presents the selected RME and CTE exposure parameter values and calculated TWFs for disturbances of soils in OU1 by park maintenance workers.

6.4.2 Investigation Summary

In 2013, outdoor ABS was conducted to determine possible exposures to City workers that maintain the park during disturbances of soil (CDM Smith 2013f). Because the construction of the remedial action at the former Export Plant (OU1) has been completed, the purpose of the 2013 outdoor ABS investigation was to collect data to support a post-construction risk assessment of the effectiveness of the remedy.

As noted above, the ABS activities focused on outdoor worker exposure scenarios because workers are expected to have greater exposure potential than recreational visitors. Two types of outdoor maintenance scenarios were evaluated at the park – mowing and weed trimming. For the mowing ABS

scenario, EPA contractors mowed the grass in Riverfront Park using walk-behind mowers[14]. For the lawn edging/weed trimming ABS scenario, EPA contractors operated a weed edger/trimmer (i.e., weed whacker). A total of three sampling events were conducted in the summer of 2013. Detailed results for the OU1 post-construction ABS investigation are presented in the *Interim Post-Construction Human Health Risk Assessment* (CDM Smith 2014e) for OU1.

6.4.3 Calculation of EPCs

Table 6-12 (Panel A) presents summary statistics for outdoor ABS air associated with disturbances of soil at OU1. Because the ABS scenarios were conducted in such a way that they are representative of the full extent of maintained park areas in OU1, there was no need to extrapolate ABS air results to un-sampled locations using soil data. Thus, it was not necessary to calculate EPCs stratified by soil concentration. EPCs were calculated separately for each type of maintenance activity.

6.4.4 Risk Estimates

Table 6-12 presents estimated cancer risks and non-cancer HQs from exposures to LA during soil disturbance activities in OU1 based on RME (Panel B) and CTE (Panel C). These results indicate that, when these exposure scenarios are considered alone, estimated RME and CTE cancer risks are below 1E-06 and non-cancer HQs are below 0.1 for both worker exposure scenarios based on post-construction conditions. It is assumed that potential risks to recreational visitors at the park would be lower than those calculated for outdoor workers. The contribution of these exposure scenarios to cumulative risk is discussed in Section 9.

However, if future excavation or construction activities occur in areas of OU1 where residual contamination remains at depth, a number of potential exposure pathways might become complete due to subsurface soil contamination. It is presumed that disturbances of residual LA contamination in subsurface soils in OU1 have the potential to result in significant exposures and risks.

6.5 Exposures in OU2

OU2 includes areas that were affected by contamination released from the former Grace Screening Plant. Subareas within OU2 include the former Screening Plant (Subarea 1), the Flyway (Subarea 2), a privately-owned property (Subarea 3), and the Rainy Creek Road frontages (Subarea 4) (see **Figure 6-5**). EPA has taken extensive actions to remove the mine-related waste materials and contaminated soils at OU2. Details of investigation and remediation activities conducted at each OU2 subarea are provided in the *OU2 RI* (EPA 2009d), the *OU2 ROD* (EPA 2010b), and the *OU2 Remedial Action Report* (EPA 2012a). Exposure to the contamination was largely mitigated by removal of surface soils and the placement of an extensive cap during removal activities prior to the OU2 ROD, with the exception of two isolated locations within the Flyway (Subarea 2), which were subsequently remediated in 2010. Residual contamination remains at varying depths over a considerable portion of OU2. Because buried residual vermiculite and contaminated subsurface soil remains at OU2, ICs are (or will be) in place that will protect the remedy and limit soil excavations to mitigate potential future exposures from contamination left at depth.

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[14] It is recognized that this type of equipment may differ from the commercial riding mowers used by City workers, but due to a lack of available equipment, this alternate mowing scenario was used. Using a walk-behind mower is considered a more conservative soil disturbance activity than a riding mower.

6.5.1 Exposure Populations and Parameters

In OU2 areas that have been remediated, and where surface soil is either capped or backfilled with clean soil, there are no complete exposure pathways to LA at present. However, there are several areas within the Flyway where soils have not been remediated. There are two receptor populations that may be exposed to LA during soil disturbance activities in the Flyway – visitors that recreate or trespass (either intentionally or inadvertently) along the Kootenai River and MDT outdoor workers that maintain the ROW along Highway 37.

Table 6-13 presents the selected RME and CTE exposure parameter values and calculated TWFs for disturbances of soils in the Flyway area of OU2.

6.5.2 Investigation Summary

Because the construction of the remedial action at the former Screening Plant (OU2) has been completed, the purpose of the 2012 outdoor ABS investigation was to collect data to support a post-construction risk assessment of the effectiveness of the remedy. Because Subarea 1 (former Screening Plant), Subarea 3, and Subarea 4 (Rainy Creek Road frontages) are all privately-owned, and the owners opted not to participate in post-construction sampling activities, the focus of the post-construction ABS investigation was on Subarea 2 (Flyway) in areas that had not been remediated, and thus have the maximum potential for exposure (i.e., "worst case").

Two ABS scenarios representative of soil disturbance activities that may take place in the Flyway were evaluated as part of the OU2 outdoor ABS investigation (CDM Smith 2012d). Scenario 1 was conducted to determine possible exposures to MDT workers that mow the ROW on the west side of Highway 37 (**Figure 6-5**). The ROW has approximately 1,500 feet of road frontage. Scenario 2 was conducted to evaluate possible exposures to individuals that recreate (e.g., hike) or otherwise trespass along river frontage in the Flyway adjacent to the Kootenai River (**Figure 6-5**). The river frontage within the Flyway is approximately 2,100 feet.

For the mowing ABS scenario, EPA contractors mowed the grass along the ROW using walk-behind mowers[15]. A total of three mowing ABS events were performed in late August/early September 2012 separated in time by one week.

For the recreational/trespass ABS scenario, two EPA contractors hiked along the river frontage stopping at obvious areas of river access when encountered, switching positions (leading/following) every five minutes as they hiked. A total of three 30-minute hiking ABS events were performed sequentially on the morning of August 21, 2012, with each ABS event taking place along different paths/routes, traversing both above and below the high water mark along the river frontage. Detailed results for the OU2 post-construction ABS investigation are presented in the *Interim Post-Construction Human Health Risk Assessment* (CDM Smith 2014f) for OU2.

6.5.3 Calculation of EPCs

Table 6-14 (Panel A) presents summary statistics for outdoor ABS air associated with disturbances of soil in the Flyway in OU2. Because the ABS scenarios were conducted in such a way that they are representative of the full extent of the potential exposure area, there was no need to extrapolate ABS

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[15] It is recognized that this type of equipment may differ from the commercial riding mowers used by MDT workers, but using a walk-behind mower is considered a more conservative soil disturbance activity than a riding mower due to the greater potential of generating dust in the breathing zone.

air results to un-sampled locations using soil data. Thus, it was not necessary to calculate EPCs stratified by soil concentration. However, because exposure conditions could differ by disturbance scenario (mowing versus hiking), EPCs were calculated separately for each type of activity. As seen, all ABS air samples were non-detect.

6.5.4 Risk Estimates

Table 6-14 presents estimated cancer risks and non-cancer HQs from exposures to LA during soil disturbance activities in OU2 based on RME (Panel B) and CTE (Panel C). As shown, because EPCs were zero, the resulting cancer risks and non-cancer HQs are also zero for all exposure scenarios in OU2 based on post-construction conditions. The uncertainty assessment (Section 10) provides additional information on risk estimates for datasets where all samples are non-detect.

However, if future excavation or construction activities occur in areas of OU2 where residual contamination remains at depth, a number of potential exposure pathways might become complete due to subsurface soil contamination. It is presumed that disturbances of residual LA contamination in subsurface soils in OU2 have the potential to result in significant exposures and risks.

6.6 Exposures in OU3

OU3 includes the property in and around the former vermiculite mine and the geographic area surrounding the mine that has been impacted by releases and subsequent migration of contaminants from the mine, including several ponds, Rainy Creek, Carney Creek, Fleetwood Creek, and the Kootenai River (see **Figure 1-5**). Rainy Creek Road is also included in OU3. Most of the land in OU3 is forested and characterized by steep and rugged terrain. Much of the land surrounding the mine is managed by the USFS, although some parcels are owned by the State of Montana and are managed by the Department of Natural Resources and Conservation.

6.6.1 Exposure Populations and Parameters

A range of different human receptor populations may be exposed to LA during soil/duff disturbances in OU3, including:

- Trespassers or "rockhounds" in the mined area – This population includes individuals who trespass on Grace's property in the area that has been disturbed by past mining activities.
- Recreational visitors in the forested area – This population includes individuals who engage in activities, such as camping, hiking, dirt bike riding, ATV riding, hunting, etc.
- Recreational visitors along rivers, streams, and ponds – This population includes individuals who hike, fish, wade/swim, or explore site drainages. In the absence of access restrictions, this might include the streams and ponds along Fleetwood Creek, Carney Creek, and Rainy Creek, as well portions of the Kootenai River that may be impacted by site releases.
- USFS firefighters in the forested area – This population includes employees of the USFS who provide ground-based response to forest fires that occur within OU3. Research has shown that firefighter activities, such as fire line construction, have the potential to result in exposures to LA when these activities are conducted in the forest near the mine (Hart *et al.* 2009).

Note that there are other potential receptor populations of interest for OU3, including local wood harvesters, USFS forest maintenance workers, and commercial loggers; however, because exposures for these populations are primarily associated with disturbances of wood-related materials, these

receptor populations are evaluated in Section 8. (Exposures to ground-based USFS firefighters are evaluated in this section, as this type of exposure scenario is mainly associated with soil/duff disturbance activities. Section 8.1.7 provides additional information on potential firefighter exposures to LA in smoke during authentic wildfires.)

Table 6-15 presents the selected RME and CTE exposure parameter values and calculated TWFs for disturbances of soil/duff in OU3.

6.6.2 Investigation Summary

Outdoor ABS air samples have been collected at OU3 as part of several sampling investigations to evaluate a variety of soil/duff disturbance scenarios. Two ABS investigations (referred to as the Phase III and Phase IV, Part A studies) were conducted to evaluate potential exposures in the forested area surrounding the mine area and along Rainy Creek. A third ABS investigation was conducted (as part of the Phase V, Part A study) to evaluate potential exposures at one of the sand bars located in the Kootenai River near the confluence with Rainy Creek. In addition, in 2014, an ABS investigation was conducted in the forested areas along the NPL boundary to try to characterize the potential nature and extent of LA contamination in the forest to inform decisions on the OU3 boundary. Each of these outdoor ABS investigations is described briefly below.

6.6.2.1 Phase III (2009)

The Phase III sampling program for OU3 (EPA 2009h) focused on the collection of ABS data to evaluate LA exposures to recreational visitors in the forested area while riding an ATV in the forest, walking or hiking in the forest, gathering firewood, clearing a fire pit area, and building/burning a campfire. A comprehensive summary of the study design and results for the Phase III study is provided in the *OU3 Data Summary Report* (CDM Smith 2013a).

A total of 11 ABS areas were selected for evaluation (see yellow shaded areas in **Figure 6-6**). These areas tended to be predominately in the downwind direction (north-northeast of the mine), and were selected based primarily on a consideration of the large-scale spatial variability of measured LA levels in forest soil, duff, and tree bark (also shown in **Figure 6-6**). For each ABS area, two Grace contractors performed the scripted recreational ABS activities. One set of ABS samples was submitted for analysis, the other set was archived. ABS events were conducted at each ABS area approximately every 10 days, starting at the end of August through the beginning of November 2009.

6.6.2.2 Phase IV, Part A (2010)

The Phase IV, Part A sampling program for OU3 (EPA 2010f) included the collection of ABS data to evaluate LA exposures to individuals driving on roads in OU3, recreational visitors hiking along Rainy Creek near the mine, and USFS firefighters while cutting fire lines in the forested area in OU3. The Phase IV, Part A sampling program also included several ABS activities related to residential wood harvesting and USFS workers; however, these data are evaluated in Section 8 as these exposures are mainly associated with wood-related disturbances. A comprehensive summary of the study design and results for the Phase IV, Part A study is provided in the *OU3 Data Summary Report* (CDM Smith 2013a). The ABS scripts for each exposure scenario related to soil/duff disturbances are described below.

Hiking. This ABS activity evaluated recreational visitor exposures while hiking along lower Rainy Creek between Highway 37 and the Grace property line (see the "LRC Study Area" in **Figure 6-7**). During each sampling event, two Grace contractors walked up the banks of the creek, disturbing bushes and other vegetation as needed to advance up the creek. Personnel switched positions

(leader/follower) after half of the sampling time had elapsed. A total of five sampling events were conducted in August 2010.

Driving. This ABS activity evaluated potential exposures to individuals while driving on roads in OU3. During each sampling event, two Grace contractors (one driver, one passenger) rode in a pickup truck with the windows open along both Rainy Creek Road and unpaved service roads to three designated wood harvesting areas in the forest within OU3 (ABS-02, ABS-07, and ABS-10; see **Figure 6-7**). A total of five sampling events were conducted in each ABS area between July and August 2010.

Firefighting. This ABS activity simulated exposures to USFS firefighters while cutting fire lines in the forested area near OU3. The script included two types of activities – a) cutting fire lines by hand using a Pulaski tool, and b) cutting fire lines using heavy equipment (e.g., a bulldozer or tractor plow). During each sampling event, two Grace contractors performed the scripted activities in each of three ABS areas in the forest within OU3 (ABS-02, ABS-07, and ABS-10; see **Figure 6-7**). A total of five sampling events were conducted in each ABS area between July and August 2010.

6.6.2.3 Phase V, Part A (2012)

The Phase V, Part A sampling program for OU3 (CDM Smith 2012e) focused on the collection of ABS data to evaluate exposures to LA by recreational visitors along the Kootenai River. The ABS was conducted on a sand bar in the Kootenai River immediately downstream of Rainy Creek. The ABS script was designed to simulate activities that are representative of actions that might be performed by local river guides and recreational visitors on the sand bar. The script was performed by two Grace contractors and included landing a boat on the sand bar, walking around and simulating an individual fishing along the edges of the sand bar, and departing by boat. ABS air samples were collected on the sandbar on the afternoon of September 19, 2012, during low-flow conditions within the Kootenai River. A comprehensive summary of the study design and results for the Phase V, Part A study is provided in the *OU3 Data Summary Report* (CDM Smith 2013a).

6.6.2.4 Nature & Extent in the Forest (2014)

As noted above, an ABS investigation was conducted in the forested areas along the NPL boundary in 2014 to characterize the nature and extent of LA contamination in the forest to inform decisions on the OU3 boundary (CDM Smith 2014g). This ABS investigation simulated exposures to USFS firefighters while cutting fire lines by hand using a Pulaski tool. During each sampling event, two ABS personnel (EPA contractors) performed the scripted activities in each of ten ABS areas in the forested areas along the NPL boundary (see **Figure 6-8**). A total of three sampling events were conducted in each ABS area in September 2014. Results of the 2014 nature and extent ABS study in the forest are summarized in CDM Smith (2014h).

6.6.3 Calculation of EPCs

Previous investigations conducted at the Site have demonstrated that LA concentrations in soil and duff in the forest areas surrounding the mine tend to be highest near the mine site and decrease as a function of distance from the mine (CDM Smith 2013a, 2013g). Because of the complex nature of the source materials in these forested areas, the difficulty in characterizing the LA concentrations in these source media, and the difficulty in establishing a reliable quantitative relationship between LA levels in source materials and ABS air, EPCs were not calculated based on source media LA concentration. Rather, EPCs were calculated as a function of distance from the mined area, and grouped into four exposure datasets – near the mine (within 2 miles of the mined area), intermediate from the mine (about 2-6 miles from the mined area), far from the mine (greater than 6 miles from the mined area), and along the NPL boundary (includes all locations evaluated in the 2014 Nature and Extent in the

Forest study described in Section 6.6.2.4). Outdoor ABS data from each ABS area within each designation were grouped together for the purposes of calculating EPCs. **Appendix F** summarizes potential exposures and risks in OU3 on an ABS area-specific basis.

For OU3 ABS studies conducted outside of the forested areas (e.g., along Rainy Creek), EPCs were calculated as the mean ABS air concentrations across the entire ABS area.

Table 6-16 presents summary statistics for outdoor ABS air associated with disturbances of soil at OU3.

6.6.4 Risk Estimates

Table 6-17 presents estimated cancer risks and non-cancer HQs from exposures to LA during soil/duff disturbance activities in OU3 based on RME (Panel A) and CTE (Panel B). These results indicate that, when these exposure scenarios are considered alone, with one exception, estimated RME and CTE cancer risks are below 1E-04 and non-cancer HQs are below 1 for all recreational and USFS firefighter exposure scenarios. For recreational visitors that hike along Rainy Creek, the RME non-cancer HQ is 2, but the CTE non-cancer HQ is below 1 and cancer risks for both RME and CTE are below 1E-04. These results show that this exposure scenario alone has the potential to exceed a non-cancer HQ of 1; however, an HQ above 1 does not necessarily mean that adverse non-cancer effects will occur. The contribution of each OU3 soil disturbance exposure scenario to the cumulative risk is discussed in Section 9.

Risk estimates could not be calculated for the "rockhound" trespasser scenario in the mined area, because there are no data on LA air concentrations that could result from this type of disturbance scenario. However, samples of soil and mine waste materials collected from the mined area show LA concentrations can be as high as 8% by PLM-VE (CDM Smith 2013a), so it is considered likely that soil disturbances in the mined area could result in potentially significant LA exposures and risks.

6.7 Exposures in OU5

OU5 includes the former Stimson Lumber Mill and all properties owned by Kootenai Business Park Industrial District (KBPID) (see **Figure 6-9**). Historically, there have been many lumber processing facilities located throughout OU5, but the majority of lumber production activities ceased in 2003 when Stimson Lumber Company sold the property to the Lincoln County Port Authority and ownership was subsequently transferred to KBPID. The majority of OU5 is un-vegetated. Several wood chip and waste bark piles from historical lumber processing activities were left onsite. OU5 is currently being redeveloped for a variety of uses, both recreational and commercial/industrial.

OU5 contains an area that has been developed as a MotoX park for dirt-biking and a recreational path along Libby Creek that is popular for hiking and bicycle riding (see **Figure 6-9**). A walking path and fishing pond in the northeast corner of OU5 near Libby Creek are planned in the future. Currently, there is no residential land use in OU5, but residential neighborhoods surround OU5 to the west and northwest.

The *OU5 RI* (HDR 2013a) summarizes the various removal efforts that have been conducted and the post-removal soil concentrations that remain. In brief, these efforts have included both removals of vermiculite and asbestos-containing materials from inside buildings as well as outdoor soil. Typically, soil removals were focused on specific areas near buildings or in locations where re-development efforts were occurring. The majority of surface soil samples collected at OU5 were non-detect for LA (PLM-VE Bin A). When LA was detected in soil, concentrations were usually trace (PLM-VE Bin B1),

but some locations have LA concentrations up to 1%. Varying levels of VV have been noted across OU5. The highest LA soil concentrations and VV levels are associated with an area that was a former tree nursery, where raw vermiculite product was added as a growth medium and fill material.

6.7.1 Exposure Populations and Parameters

There are two main types of receptor populations of interest for the purposes of evaluating exposures to LA during soil disturbances in OU5 – recreational visitors and outdoor workers.

Recreational visitors include individuals that hike or bicycle on the recreational path along Libby Creek and individuals that use the MotoX Park. It is assumed that exposures to hikers and bicyclists on the recreational path are likely to be similar; thus, only one type of recreational receptor is evaluated for this exposure scenario. Because potential exposures concentrations could differ between adult bicycle riders and children in trailers attached to the back of the bicycle, exposures are determined separately for each scenario.

There are two types of individuals that are likely to use the MotoX Park – riders and spectators. Information on exposure parameters for riders at the MotoX Park was obtained from six volunteers who participated in the MotoX Park ABS investigation (EPA 2008e). **Appendix G** presents the results of the MotoX Park survey. Risk estimates for participants at the MotoX Park are based on the exposure parameters derived from the volunteer responses.

As noted above, OU5 may be re-developed for a variety of commercial and/or industrial uses (future residential use is not expected). Thus, exposure parameters for outdoor workers were based on a default industrial worker scenario. However, default exposure values were adjusted to focus on the exposure interval when soil disturbances are occurring (i.e., a worker may be outdoors 8 hours/day, but it is unlikely that they would be disturbing soil over this entire time interval). It was assumed that outdoor workers would engage in soil disturbance activities for about one-half the work day (i.e., 4 hours/day).

Table 6-18 presents the selected RME and CTE exposure parameter values and calculated TWFs for disturbances of soils in OU5.

6.7.2 Investigation Summary

Three different outdoor ABS investigations were conducted at OU5 in September/October of 2008 to evaluate potential exposures to LA during soil disturbance activities. Each of the outdoor ABS investigations is described briefly below.

6.7.2.1 Recreational Visitors

In September of 2008, two outdoor ABS studies were performed to evaluate potential exposures to recreational visitors in OU5 from soil disturbance activities.

The first study was conducted at the MotoX Park (see **Figure 6-10**) to evaluate potential exposures to motorcycle riders and spectators during park use (EPA 2008e). Soil samples collected at the MotoX Park show a mixture of PLM-VE Bin A (non-detect) and Bin B1 (trace) conditions at the track. During each of two sampling events, two types of air monitoring samples were collected: 1) personal air monitors were mounted to the handle bars of the motorcycles for several volunteer riders (see **Figure 2-2** for an example photograph of this ABS activity), and 2) five stationary air monitors were placed around the perimeter of the track to characterize potential exposures to spectators.

The second study was conducted to evaluate potential exposures to bicycle riders on the recreational path adjacent to Libby Creek (see **Figure 6-10**) (EPA 2008f). On four separate days, three EPA contractors wore personal air monitors while bicycling along the entirety of the path. Sampling was conducted separately for the paved and unpaved portions of the path. On the paved path[16], an air monitor was also mounted in a trailer attachment to one of the bicycles to characterize potential exposures to a young child.

6.7.2.2 Outdoor Workers

As part of the OU5 outdoor worker ABS investigation, sampling was conducted at eight ABS areas in September/October of 2008 (EPA 2008g). Each ABS area was approximately 1-1.5 acres in size. These eight ABS areas were selected based on previously reported VV conditions to represent the range of expected soil contamination conditions at the OU5 site, with Area 1 representing the low end of the soil range and Area 8 (the former tree nursery) representing the high end of the range (see **Figure 6-10**). During each of three separate sampling events, two workers wore personal air monitors while performing an outdoor ABS script to simulate soil disturbance activities at each ABS area. The outdoor worker ABS script included a 120-minute scenario split equally into raking activities and bobcat operation activities. At the time of each sampling event at each ABS area, 30 grab samples and one 30-point composite soil sample were collected[17]. During the soil sample collection, the field team recorded information on VV for each sampling point (i.e., 30 grab sampling points and 30 composite sampling points).

6.7.3 Calculation of EPCs

6.7.3.1 Recreational Visitors

Because the MotoX and bicycle riding ABS scenarios were conducted in such a way that they are representative of the full extent of the MotoX track and bike path in OU5, there was no need to extrapolate ABS air results to un-sampled locations using soil data. Thus, it was not necessary to calculate EPCs stratified by soil concentration. For the bicycling scenario, EPCs were calculated separately for adult riders and trailers. **Table 6-19** (Panel A) presents the calculated EPCs associated with disturbances of soil at the MotoX Park and while riding bicycles in OU5.

6.7.3.2 Outdoor Workers

As described above, there were eight ABS areas selected for evaluation based on previously reported LA soil concentrations and VV conditions to represent the range of expected soil contamination conditions at OU5 (see **Figure 6-10**). For the purposes of estimating risks, EPCs were calculated separately for each ABS area to illustrate the potential range of exposure conditions. **Table 6-19** (Panel A) presents the calculated EPCs associated with disturbances of soil during worker activities in OU5 for each ABS area.

6.7.4 Risk Estimates

Table 6-19 presents estimated cancer risks and non-cancer HQs from exposures to LA during soil disturbance activities in OU5 based on RME (Panel B) and CTE (Panel C). As shown, these results indicated that, when the recreational visitor exposure scenarios are considered alone, estimated RME and CTE cancer risks are below 1E-06 and non-cancer HQs are below 0.1 for all scenarios, including

[16] Samples from the trailer were not collected from the unpaved portion of the path because the unpaved portion of the path was steep and narrow in sections, and not safe for pulling a trailer.

[17] Due to the high frequency of non-detect soil results, PLM-VE analyses were only performed for a subset of soil samples collected as part of the ABS investigation; 451 of 744 soil samples (61%) were analyzed, the remainder were archived.

while riding bicycles along bike path, while riding motorcycles at the MotoX Park, and while observing riders at the MotoX Park.

For exposures to outdoor workers, when this exposure scenario is considered alone, estimated RME cancer risks are below 1E-04 and non-cancer HQs are at or below 1 for all ABS areas (Area 5 had an HQ of 1). Estimated CTE cancer risks are at or below 1E-05 and non-cancer HQs are below 1 for all ABS areas.

The contribution of the OU5 soil disturbance exposure scenarios to cumulative risk is discussed in Section 9.

6.7.5 Extrapolation to Areas Without Outdoor Worker ABS

The OU5 Site encompasses about 400 acres. Because it is not feasible to evaluate outdoor worker risks by conducting ABS sampling on every acre, it was necessary to use the ABS data from the eight ABS areas that have been investigated to draw risk conclusions about areas that have not been studied by ABS. This was done by assessing the degree to which soil results from other areas are similar to the soil results for areas with ABS data.

Figure 6-10 illustrates the LA soil concentrations at OU5 based on PLM-VE results. A four-color scheme is used to indicate the data: green = Bin A (non-detect), yellow = Bin B1 (trace), orange = Bin B2 (<1%), red = Bin C (≥1%). In this figure, individual grab samples (primarily collected within the outdoor worker ABS areas) are shown as triangles, and composite samples are shown as circles plotted at the mid-point[18] of the sample collection area. The OU5 outdoor worker ABS specifically targeted ABS areas to encompass the full range of expected levels of LA soil contamination at OU5. As shown, LA soil concentrations outside of the ABS areas are similar to or lower than concentrations inside the ABS areas. These data support the conclusion that outdoor worker exposures and risks across OU5 from soil disturbances are likely to be similar to, or lower than, exposures and risks calculated for the ABS areas.

6.8 Exposures in OU6

6.8.1 Exposure Populations and Parameters

OU6 is owned by the BNSF railroad and is defined geographically by the BNSF property boundaries from the eastern boundary of OU4 to the western boundary of OU7, including the Libby and Troy rail yards. Thus, the primary receptor population of interest for OU6 is BNSF railroad workers who may be exposed to LA during soil disturbances along the railroad tracks as a consequence of regular rail maintenance activities. In addition, local on-lookers or pedestrian trespassers may also be exposed during these maintenance activities.

The ambient air evaluation (Section 5) addressed potential exposures of individuals that reside near railroad tracks, as two of the ambient air monitoring stations were intentionally placed near rail lines in OU6 (see **Figure 5-1**).

Table 6-20 presents the selected RME and CTE exposure parameter values and calculated TWFs for disturbances of soils in OU6.

[18] Composite samples are representative of a larger area beyond the plotted point presented in this figure.

6.8.2 Investigation Summary

BNSF performed outdoor ABS in September 2008 (EMR Inc. 2010a, b) to measure the concentration of LA released into air during railroad maintenance activities along the OU6 rail corridor. This ABS study was designed to evaluate potential exposures to BNSF workers and the general public. The worker scenario simulated two types of railroad workers: a general laborer performing duties on the track as part of larger group of workers and workers operating machinery with an open air cab. Two types of public exposure scenarios were planned: on-lookers and pedestrian trespassers; however, due to manpower limitations when the ABS was conducted, the two scenarios were essentially the same.

ABS was conducted by BNSF contractors at seven locations along a 30 mile stretch of rail line in OU6, from mile post (MP) 1312 to MP 1341 (see **Figure 6-11**) in areas of planned rail maintenance activities. These ABS samples underwent a supplemental TEM analysis to improve the achieved analytical sensitivity in 2013. Detailed results of the BNSF ABS investigation for OU6 (including the supplemental analyses) are presented in CDM Smith (2014i) and Kennedy/Jenks Consultants (2014).

The outdoor ABS samples collected in 2008 were determined to be representative of exposure conditions that are reasonably expected to be present in OU6 at the time of the study (2008) and under present conditions. This conclusion is based on the fact that, in general, removal actions within OU6 were completed prior to 2008. As such, the 2008 outdoor ABS air samples are likely to be representative of conditions that could reasonably be encountered by current and future workers and the general public within OU6.

6.8.3 Calculation of EPCs

Table 6-21 (Panel A) presents summary statistics of the OU6 outdoor ABS investigation results. As seen, all ABS air samples were non-detect. The mean air concentration (i.e., a concentration of zero) was used as the EPC in the risk calculations.

6.8.4 Risk Estimates

Table 6-21 presents estimated cancer risks and non-cancer HQs from exposures to LA during soil disturbance activities in OU6 based on RME (Panel B) and CTE (Panel C). As shown, because EPCs were zero, the resulting cancer risks and non-cancer HQs are also zero for all exposure scenarios. The uncertainty assessment (Section 10) provides additional information on risk estimates for datasets where all samples are non-detect.

Although ABS data are not available for all 40 miles of the rail line at the Site, it is considered likely that the ABS data that are available are representative of conditions along most of the line. Barring any train car derailments (the historical documentation that has been reviewed does not indicate any such events), outside of the train car loading area (which has already been addressed by prior soil removal actions), there is no reason to expect that contamination levels are spatially dependent as a function of distance along the rail line (i.e., if spillage were occurring due to railcar jostling, contamination at mile A should be similar to mile B). Based on this conceptual model of contamination, the risk estimates are likely to be applicable to the entire rail line within OU6.

6.9 Exposures in OU8

6.9.1 Exposure Populations and Parameters

OU8 includes roads and ROWs[19] within Libby and Troy. Individuals that drive on highways, roads (paved and unpaved), and alleys in Libby and Troy have the potential to be exposed to LA while driving. As noted previously, for the purposes of the risk assessment, air inside vehicles is evaluated as outdoor air that may be influenced by disturbances of soil (e.g., airborne roadway dust). The two primary populations of interest that have the potential to be exposed to LA during soil disturbances in the ROW include outdoor workers that maintain the ROW (e.g., mowing or brush-clearing) and individuals that walk, bike, or ride ATVs along the ROW.

Table 6-22 presents the selected RME and CTE exposure parameter values and calculated TWFs for disturbances of soils in OU8.

6.9.2 Investigation Summary

6.9.2.1 While Driving on Roads in Libby and Troy

Two different ABS investigations have been conducted to evaluate potential exposures while driving on roads at the Site. In 2010, an investigation was performed by EPA to evaluate exposures in Libby (CDM Smith 2010b). In 2011, an analogous investigation was performed by DEQ to evaluate exposures in Troy (Tetra Tech 2011).

For both investigations, the driving activity was conducted by an EPA or DEQ contractor driving a full size automobile (car or truck). Both paved roads and unpaved roads/alleys were traveled, with travel evenly distributed throughout the OU. The contractor maintained a reasonable speed during the activity, following all posted speed limits. During sample collection, the two front windows of the vehicle were fully open, and the two back windows were open approximately 1 inch. All samples were collected from the right shoulder of the contractor. The specific driving routes were documented utilizing a portable global positioning system (GPS) unit to record the route.

In Libby, a total of 20 two-hour driving events were conducted in the summer of 2010. Because it was not possible to travel every road within OU4 during each sampling event, each event covered areas missed in previous events such that the sum of all 20 events comprehensively covered most of the roads in Libby. **Figure 6-12** provides a map of the roads that were traveled during the driving ABS events in Libby. ABS air samples were originally analyzed in 2010; a subset of the samples underwent a supplemental TEM analysis to improve the achieved analytical sensitivity in 2013. Detailed results of the Libby driving ABS investigation (including the supplemental analyses) are summarized in CDM Smith (2014a).

In Troy, a total of 10 one-hour driving events were conducted in the summer of 2011. Each event included driving once along most of the roads in Troy and multiple times along more commonly-traveled roads. **Figure 6-13** provides a map of the roads that were traveled during the driving ABS events in Troy. Detailed results of the Troy driving ABS investigation are summarized in Tetra Tech (2013).

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[19] Excludes the ROW along Highway 37 in OU2.

6.9.2.2 Along Road Right-of-Ways

In 2010 and 2011, EPA performed outdoor ABS studies to measure levels of LA in air under a variety of soil disturbance activities that could occur in OU8 ROWs (TechLaw, Inc. 2010). Specifically, outdoor ABS data were collected while ATV riding, mowing, and brush-clearing in the ROW along a segment of Highway 37 (see **Figure 6-14**). Outdoor ABS data were also collected while rotomilling (i.e., road resurfacing) along Highway 37 between Highway 2 and East 2nd Street. ABS locations were selected based on VV field observations and PLM-VE soil results, intentionally selecting locations with higher levels of LA, in proximity to the town of Libby, and actual areas of expected exposure activities. Detailed results of the OU8 ROW ABS investigation are summarized in the *OU8 RI* (HDR 2013b).

6.9.3 Calculation of EPCs

Because the driving ABS scenarios were conducted in such a way that they are representative of most roads and alleys in Libby and Troy, there was no need to extrapolate ABS air to un-sampled locations based on soil concentration. However, because road conditions may differ between Libby and Troy, EPCs were calculated separately for each city. EPCs for each city were calculated as the average air concentration across all sampling events.

For the ROW outdoor ABS studies, because each type of disturbance activity could result in different releases and because the exposure populations could differ by activity type, EPCs were calculated separately by disturbance activity (i.e., separate EPCs were calculated for ATV riding, brush-clearing, and rotomilling).

Table 6-23 (Panel A) presents the calculated EPCs associated with disturbances of soil while driving on roads in Libby and Troy and in the OU8 ROWs.

6.9.4 Risk Estimates

Table 6-23 presents estimated cancer risks and non-cancer HQs from exposures to LA during soil disturbance activities along roadways and while driving based on RME (Panel B) and CTE (Panel C). As shown, these results indicate that, when these exposure scenarios are considered alone, estimated RME and CTE cancer risks are at or below 1E-05 and non-cancer HQs are below 1 for all exposure scenarios. The contribution of the OU8 soil disturbance exposure scenarios to cumulative risk is discussed in Section 9.

For the ROW outdoor ABS studies (ATV riding/brush-clearing), because ABS was only conducted on smaller segments of the ROWs in OU8, it was necessary to extrapolate ABS results to ROW segments that had not been sampled using ABS. This was achieved by assessing the degree to which soil results from un-sampled areas were similar to the soil results for the ABS areas. Because the segments selected for ABS were selected to be representative of the highest soil concentrations (see **Figure 6-14**), measured ABS concentrations are likely to represent "worst case" exposure conditions. Thus, it is expected that potential risks along the ROW in segments that were not evaluated as part of the ABS study are likely to be lower than those presented in **Table 6-23**.

6.10 Evaluation of Background LA Levels in Soil

EPA has performed extensive outdoor ABS investigations at the Site, seeking to characterize airborne levels of LA that occur in association with soil disturbance activities. In some cases, these studies have detected LA fibers in ABS air samples collected in locations where the soil is not expected to have mine-related contamination (EPA 2010d; CDM Smith 2014b). This raises the possibility that there is some "non-zero" level of LA in soils of the Kootenai Valley that is not attributable to anthropogenic

releases from vermiculite mining and processing activities. Under Section 104(a)(3)(A) of CERCLA, EPA cannot clean up soils to a concentration lower than background; therefore, it is important for risk managers to understand the nature and magnitude of these naturally-occurring levels (EPA 2002b).

EPA has conducted several investigations at the Site to characterize LA in soil from areas that are thought to be representative of "background" conditions. The term "background" is used to refer to soils that are not expected to be affected by anthropogenic releases from vermiculite mining and processing activities. A detailed discussion and evaluation of the investigations that have been performed to characterize background levels of LA in soil is presented in the *Background Soil Summary Report* (CDM Smith 2014j).

6.10.1 LA Concentrations in Background Soil

In most of the background soil investigations, soil concentrations of LA were measured by TEM following preparation of the soil using a fluidized bed asbestos segregator (FBAS). FBAS is a technique for evaluating low level asbestos concentrations in soil. Following FBAS preparation, TEM soil analyses are able to achieve detection limits less than 0.005% by mass (Januch *et al.* 2013), which is approximately 100-times lower than the detection limits that are reliably achieved using other analytical methods (e.g., PLM).

The results of these background soil characterization studies show that LA structures have been consistently detected in background soils within the Kootenai Valley that are not thought to be affected by anthropogenic releases from vermiculite mining and processing activities. While background soil concentrations are variable (see **Figure 6-15**), in general, the average total LA concentration is about 5E+05 structures per gram of soil (s/g), which is estimated to be approximately 0.014% LA by mass (CDM Smith 2014j). This concentration is well below the reliable detection limit of traditional analytical methods for soil used at the Site (i.e., PLM-VE).

6.10.2 Outdoor Air Concentrations During Background Soil Disturbances

As discussed previously, the detection of LA in background soil does not necessarily indicate that human exposures to LA released to air during disturbances of background soil would result in unacceptable exposures or risks. Thus, several ABS studies were performed to measure LA concentrations in air during disturbances of background soils. In most of the background soil investigations, a digging ABS scenario was performed using soils collected and composited in a five-gallon container; hence, this ABS scenario is referred to as the "bucket of dirt" digging scenario. The five-gallon container was brought to a specified location where the ABS soil digging scenario was conducted. The digging activity was performed using a hand trowel, simulating a child digging and playing in the dirt (see **Figure 6-16**).

The results of the "bucket of dirt" digging ABS studies are summarized in **Table 6-24** (Panel A) and presented graphically in **Figure 6-17**. As indicated, measured LA concentrations in ABS air tend to be highly variable but concentrations released from background soils from Libby and Troy are generally similar and somewhat higher than concentrations for topsoil borrow sources within the Kootenai Valley.

The "bucket of dirt" digging ABS scenario is likely to represent the high-end of potential exposures and may not be a realistic estimate of exposures that could occur under authentic soil disturbance activities, such as raking, mowing, and digging activities in residential yards. In order to provide data on potential LA exposures from background soil under less vigorous disturbance scenarios that are more likely to be representative of scenarios that apply to residents, EPA conducted an outdoor ABS

investigation at residential properties in OU4 where a "curb-to-curb" soil removal had occurred (i.e., the entire yard had been removed and replaced with topsoil fill material) (CDM Smith 2014b). A total of 11 residential properties were evaluated as part of the curb-to-curb outdoor ABS investigation. Three sampling events[20] were conducted at each property in the summer of 2011. For each sampling event, a single ABS air sample was collected from each property, representing a composite of three yard soil disturbance activities – mowing, raking, and digging. The mowing portion of the composite represented a one-pass mowing of the entire yard. The raking portion of the composite represented a one-pass raking of the entire yard. The digging portion of the composite simulated a sprinkler maintenance activity at each of two to six locations (i.e., digging a hole with a long shovel and trowel). **Table 6-24** (Panel A) summarizes the results of the curb-to-curb outdoor ABS study. These data are presented graphically in **Figure 6-17**.

6.10.3 Risk Estimates

Table 6-24 (Panel B) presents estimated RME cancer risks and non-cancer HQs for exposures to LA in outdoor ABS air for the "bucket of dirt" digging ABS scenarios and at curb-to-curb properties (i.e., during soil disturbances), assuming exposure parameters for residential yard soil disturbance (see **Table 6-1**). As shown, estimated RME and CTE cancer risks are below 1E-05 and non-cancer HQs are below 1 for all ABS datasets. For the curb-to-curb properties, the estimated RME cancer risk is 2E-06 and non-cancer HQ is 0.1. These estimated risks are the same those calculated for residential yards where the soil concentrations are non-detect by PLM-VE (Bin A) (see **Table 6-3a**). These results demonstrate that a portion of the total exposure from soil disturbances at the Site may be attributable to background levels of LA in soil.

6.11 Overall Risk Conclusions

In reviewing the risk calculation tables for exposures during soil disturbance activities, there are a number of general conclusions that can be drawn:

- Estimated cancer risks and non-cancer HQs span more than four orders of magnitude depending upon the exposure scenario.
- For a given exposure scenario, non-cancer HQs can exceed 1 even when cancer risks are less than 1E-04, which indicates that non-cancer exposure is a more sensitive metric of potential concern. For example, recreational visitor exposures while hiking along Rainy Creek yielded an estimated excess cancer risk of 4E-05 and a non-cancer HQ of 2 (based on RME) (see **Table 6-17**). (For LA, a non-cancer HQ of 1 is approximately equivalent to a cancer risk of 1E-05.)
- More than 80 different types of exposure scenarios during soil disturbances were evaluated, encompassing a wide range of disturbance activities, OUs, exposure locations, and soil concentrations. With one exception (outdoor worker exposures during yard soil disturbances with Bin B2/C concentrations), there were no individual soil disturbance exposure scenarios where CTE cancer risks exceeded 1E-04 or non-cancer HQs exceeded 1. However, there were four individual soil disturbance exposure scenarios where RME cancer risks exceeded 1E-04 and/or non-cancer HQs exceeded 1, including:

[20] At one property, the resident agreed to participate in only one sampling event.

- Residential exposures during disturbances of yard soils with detected LA at properties in OU4 and OU7 (see **Table 6-3a**)
- Outdoor worker exposures during disturbances of yard soils with detected LA at residential and commercial properties in OU4 and OU7 (see **Table 6-3b**)
- Outdoor worker exposures during disturbances of subsurface soils with residual LA contamination at residential and commercial properties in OU4 and OU7 (see **Table 6-5**)
- Recreational visitor exposures while hiking along Rainy Creek in OU3 (see **Table 6-17**)

- Quantitative risks were not calculated for potential exposures to trespassers in the mined area or for workers exposed to residual LA in subsurface soils in OU1 and OU2; however, these exposure scenarios are presumed to result in potentially significant exposures and risks.
- Exposure to LA in outdoor air during yard soil disturbances has the potential to be an important exposure scenario. Even when only trace levels of LA are present in the soil (i.e., PLM-VE Bin B1), this exposure scenario, when considered alone, could yield RME non-cancer HQs above 1, depending upon the spatial extent of the LA in soil and the frequency and intensity that these soils are disturbed.
- LA structures have been consistently detected in background soils within the Kootenai Valley that are not thought to be affected by anthropogenic releases from vermiculite mining and processing activities. ABS activities conducted on these background soils demonstrate LA can be released to air; however, estimated risks from background soil exposures appear to be low (i.e., cancer risk below 1E-05 and non-cancer HQ below 1).
- Estimated exposures and risks during yard soil disturbances when LA is not detected in soil (i.e., PLM-VE Bin A) are similar to those calculated for background soils.

There are several soil disturbance exposure scenarios where the ABS dataset was all non-detect (i.e., EPCs and estimated risks are zero) or the number of samples with detected PCME LA structures was limited. The uncertainty assessment (Section 10) provides additional information on risk estimates for datasets where all samples were non-detect or where the LA detection frequency was low.

Section 7

Risks from Exposures to Indoor Air

This section summarizes the results of studies performed at the Site to evaluate potential exposures to LA in indoor air, describes how these data are used to calculate exposures, and presents estimated cancer risks and non-cancer HQs for several potential exposure scenarios. This section is organized by receptor type and exposure location as follows:

- Section 7.1 - Residential and indoor worker exposures inside properties in OU4 and OU7
- Section 7.2 - Tradesperson exposures inside properties in OU4 and OU7
- Section 7.3 - Student and teacher exposures inside schools in OU4
- Section 7.4 - Worker exposures inside the David S. Thompson Search and Rescue building in OU1
- Section 7.5 - Worker exposures inside buildings in OU5

There have been several indoor ABS investigations to evaluate LA concentrations in air during various indoor disturbance scenarios. **Table 2-2** (Panel C) summarizes the types of indoor ABS investigations that have been conducted. The following sections summarize the indoor ABS datasets that provide information on each indoor exposure scenario. The following sections also present the selected RME and CTE exposure parameter values and calculated TWFs for each exposure scenario. Each section identifies the basis of the selected exposure parameters and notes if any Site-specific adjustments were applied. It is important to note that the exposure parameters and resulting TWFs are selected for the purposes of evaluating potential risks from each individual exposure scenario (i.e., the cumulative assessment may utilize different TWFs).

7.1 Residential/Commercial Exposures Inside Properties in OU4 and OU7

7.1.1 Exposure Populations and Parameters

There are two main exposure populations of interest for the purposes of evaluating potential exposures to LA inside properties in OU4 and OU7 – residents and indoor workers. As described previously in Section 2.1.2, indoor workers may include office administrative assistants, shop keepers, restaurant staff, etc. For both indoor workers and residents, there are a wide range of different activities that could occur inside properties. For the purposes of evaluating exposures in the risk assessment, parameters were determined separately for exposures under active and passive conditions. Active behaviors include indoor activities in which a person is moving about the building and potentially disturbing indoor sources; such activities have included walking from room to room, sitting down on upholstered chairs, sweeping, and vacuuming. Passive behaviors are minimally energetic actions, such as sitting and reading a book, watching television, and working at a desk, that will have low tendency to disturb any indoor source materials.

Table 7-1 presents the selected RME and CTE exposure parameter values and calculated TWFs for evaluating potential residential and indoor worker exposures inside properties in OU4 and OU7.

7.1.2 Investigation Summary

There have been four different indoor ABS investigations conducted in OU4 and one indoor ABS investigation in OU7. As part of these studies, indoor ABS air samples were collected under active and/or passive conditions. Each of these studies is described briefly below.

In 2001, indoor ABS was conducted as part of the Phase 2 investigation in OU4. During this ABS program, indoor ABS was performed during active cleaning and/or passive behaviors at 24 properties. Samples of indoor dust were also collected at each property. ABS air samples were originally analyzed in 2001; a subset of the samples underwent a supplemental TEM analysis as part of the OU4 SQAPP investigation (see below) to improve the achieved analytical sensitivity in 2005. The original Phase 2 indoor ABS results are summarized in EPA (2006d); supplemental analysis results are summarized in EPA (2007a).

In 2005, indoor ABS was conducted as part of the OU4 SQAPP investigation (EPA 2005b). Indoor ABS samples (both personal and stationary monitoring samples) were collected under routine (passive) living conditions over a period of about 8 hours. In addition to collecting indoor ABS air, samples of indoor dust were also collected at each property. Results of the OU4 SQAPP indoor ABS results are summarized in EPA (2007a).

The largest indoor ABS program in OU4 occurred from 2007-2008 (EPA 2007e). During this ABS program, indoor ABS was performed during active and passive behaviors at 81 properties. The properties evaluated included those where an outdoor soil removal had already been performed or where no outdoor soil removal was deemed necessary at that time with varying levels of LA in the outdoor soil, because it was hypothesized that outdoor soil concentrations of LA may be an important predictor of LA concentrations in indoor air. At each property, four rounds of ABS were conducted, such that the resulting data were representative of each season (summer, fall, winter, spring). Indoor dust samples were collected during each sampling event; outdoor soil samples were collected during the summer event for each property. Results of the 2007-2008 OU4 indoor ABS investigation are summarized in (EPA 2010d).

In 2013, two different indoor ABS scenarios were evaluated in OU4 (CDM Smith 2013h). During this ABS program, indoor ABS was performed during active and passive behaviors at 20 properties. In the first scenario, indoor ABS was conducted at 10 properties in OU4 where a “curb-to-curb” yard soil removal had been completed. Two rounds of ABS were conducted; one in the winter and one in the summer. In the second scenario, 10 of the 81 indoor ABS properties originally sampled in 2007-2008 were re-sampled in the summer of 2013. Results of the 2013 OU4 indoor ABS investigation are summarized in CDM Smith (2013i).

For OU7, an indoor ABS program was conducted in 2012 and 2013 to evaluate potential exposures during active and passive behaviors at 20 properties (Tetra Tech 2012b). The properties selected for evaluation included properties where removals had already been performed (an interior removal, an exterior removal, or both), as well as properties where no removal was deemed necessary at that time, with varying levels of LA in the outdoor soil. At each property, two rounds of ABS were conducted, such that the resulting data were representative of summer and winter conditions (collected in September 2012 and February/March 2013, respectively). Results of the OU7 indoor ABS investigation are summarized in Tetra Tech (2014).

7.1.2.1 Role of Source Material Information in Evaluating Indoor Risks

Because it is not feasible to evaluate risks by conducting indoor ABS at every property in OU4 and OU7, it is necessary to use the measured ABS data from the properties where ABS has been performed to draw risk conclusions about properties where ABS has not been performed. Recall that for outdoor ABS associated with disturbances of soil, this was done by grouping the outdoor ABS air results by LA concentrations in soil (i.e., PLM-VE bins). For indoor ABS, various strategies have been attempted to correlate indoor ABS air concentrations with LA levels in indoor dust and outdoor soil (EPA 2007a, 2010d). However, these attempts have had limited success.

A priori, it was expected that indoor dust would be the main source of LA in indoor air. However, no clear correlation could be detected. The reason for the lack of observable correlation between indoor dust and indoor ABS air is not certain. One possible explanation is that the relationship between dust levels and air levels is dependent on building-specific random variables, such as heating source, carpet age, number of pets, cleaning frequency, etc., which would result in extreme variability in the relationship. Another possible explanation is that the dust samples collected from horizontal surfaces and high traffic areas may not be the main source of LA in indoor air, and dust from other parts of the house (e.g., from upholstered furniture, air ducts) represents the main source (EPA 2007a).

There does appear to be a weak correlation between outdoor soil and indoor ABS air. However, regression analysis suggests that other sources besides outdoor soil are likely to be a larger contributor to indoor ABS air concentrations of LA (EPA 2010d).

For these reasons, indoor ABS air data were not grouped based on either indoor dust or outdoor soil concentrations. Rather, data were grouped based on the interior removal status information (see below).

7.1.2.2 Role of Interior Removal Status Information in Evaluating Indoor Risks

Since 2000, nearly 1,000 interior removals have been completed at properties in OU4 and OU7 as part of the emergency response removals. The nature of the interior removal efforts performed depended upon the types of source materials present at the property, the levels of LA in these materials, as well as the presence of VV inside the property. For the purposes of grouping the indoor ABS data, ABS air samples for each property were classified into three removal status categories based on property conditions at the time of the ABS:

- **Pre-removal:** An interior removal was performed at this property; ABS data reflect property conditions prior to the removal being completed.
- **Post-removal:** An interior removal was performed at this property; ABS data reflect property conditions after the removal was completed.
- **No removal required:** This property was evaluated and no interior removal was deemed necessary at the time of the ABS.

7.1.2.3 Calculation of EPCs

7.1.2.3.1 Accounting for Seasonal Patterns

Figure 7-1 presents the average active and passive indoor ABS air concentrations by season as measured during the 2007-08 indoor ABS study in OU4. As shown, indoor ABS air concentrations of LA tend to vary temporally, with concentrations tending to be highest in summer and lowest in winter. This is perhaps due to the interaction between outdoor ambient air and indoor air (recall that a

similar temporal pattern was seen for ambient air, see **Figure 5-6**). Because of this temporal variability, and because the sampling frequency has not been equal across seasons, for the purposes of calculating long-term average exposures over multiple years, the indoor ABS air EPC was calculated using the following approach:

$$EPC = \sum \bar{X}_i \cdot 1/4$$

where:

EPC = Long-term average indoor ABS air exposure point concentration (PCME LA s/cc)

$\bar{X}_i$ = Average indoor ABS air concentration for season 'i' (PCME LA s/cc)

1/4 = One season weighting factor

For the purposes of this calculation, seasons were defined as follows:

- Spring: March, April, May
- Summer: June, July, August
- Fall: September, October, November
- Winter: December, January, February

Table 7-2 presents summary statistics of the measured TEM air concentrations for active and passive behaviors for each interior removal status category for OU4 and OU7.

7.1.2.3.2 Accounting for Different Indoor Disturbance Behaviors

Because it is expected that individuals may engage in a range of indoor behaviors (active and passive), to account for differences in behavior types in long-term exposure estimates, both EPC values were used in the risk estimates, but were time-weighted as follows:

$$Risk = (EPC_{active} \cdot TWF_{active} \cdot IUR_{LA}) + (EPC_{passive} \cdot TWF_{passive} \cdot IUR_{LA})$$

$$HQ = (EPC_{active} \cdot TWF_{active} / RfC_{LA}) + (EPC_{passive} \cdot TWF_{passive} / RfC_{LA})$$

where:

EPC_{active} = Exposure point concentration, during active behaviors (PCME LA s/cc)

TWF_{active} = Time-weighting factor for active behaviors (unitless)

$EPC_{passive}$ = Exposure point concentration, during passive behaviors (PCME LA s/cc)

$TWF_{passive}$ = Time-weighting factor for passive behaviors (unitless)

7.1.3 Risk Estimates

Table 7-3 presents the estimated cancer risks and non-cancer HQs for residential and indoor worker exposures to LA in indoor air in OU4 and OU7 based on RME (Panel A) and CTE (Panel B). As shown, with the exception of indoor exposures at "pre-removal" properties (discussed below), when these exposure scenarios are considered alone, estimated RME and CTE cancer risks are below 1E-04 and non-cancer HQs are below 1 for all exposure scenarios.

Non-cancer HQs are greater than 1 (based on RME) for both residential and commercial exposures to LA inside "pre-removal" properties in OU4 (properties where an interior removal was deemed necessary, but a removal had not been completed at the time of the ABS). Activities associated with active disturbance behaviors contributed most to total exposures, compared to passive disturbance behaviors (see **Table 7-3** Panel A). Non-cancer HQs are below 1 based on CTE (see **Table 7-3** Panel B). Although no indoor ABS data are available for pre-removal properties in OU7, it is expected that the conclusions based on OU4 data would also apply to OU7.

Non-cancer HQs for "post-removal" properties are below 1 based on RME (see **Table 7-3** Panel A). These results demonstrate that interior removals have been effective at mitigating sources of LA inside the property. Additionally, non-cancer HQs for "no removal required" properties are also below 1 based on RME, which indicates that interior property assessments performed by the field teams are effective at identifying when removal efforts are not needed.

7.2 Tradesperson Exposures Inside Properties in OU4 and OU7

7.2.1 Exposure Populations and Parameters

Previous investigations conducted at the Site have demonstrated that LA may be present in VI and building materials in residential and commercial properties in OU4 and OU7. Thus, another population of interest for evaluating exposures to LA inside properties are local tradespeople, such as local contractors, electricians, or plumbers, that may come into direct contact with LA-containing building materials (e.g., VI) while engaging in occupational activities.

Table 7-1 presents the selected RME and CTE exposure parameter values and calculated TWFs for evaluating potential tradesperson exposures inside properties in OU4 and OU7.

7.2.2 Investigation Summary

In accordance with Occupational Safety and Health Administration (OSHA) requirements, during indoor removal activities, health and safety (H&S) monitoring of EPA-contracted workers is performed during various types of removal activities and samples are analyzed by PCM (see Section 2.3.2). A subset of the archived H&S air monitoring samples from properties in OU4 were re-analyzed by TEM in 2012 to support an evaluation of potential risks to local tradespeople from inhalation of LA during disturbances of indoor source materials (CDM Smith 2012b). These samples were selected to represent a range of indoor removal activities, including low intensity disturbances (e.g., wet-wiping and vacuuming living spaces using a high-efficiency particulate air [HEPA] vacuum, attic detailing) and high intensity disturbances (e.g., removal of bulk VI, wall demolition).

Detailed results from the H&S air sample re-analysis effort are presented in CDM Smith (2013j). **Table 7-4** presents summary statistics of the measured TEM PCME air concentrations for each type of indoor removal activity. The mean air concentration for each type of removal activity was used as the EPC in the risk calculations.

7.2.3 Risk Estimates

Table 7-5 presents the estimated cancer risks and non-cancer HQs for tradesperson exposures to LA in indoor air at residential and commercial properties in OU4 and OU7 based on RME (Panel A) and CTE (Panel B). As shown, exposures of local tradespeople have the potential to result in RME non-cancer HQs above 1 for every disturbance activity evaluated, with HQs ranging from 4 to 20, depending upon the activity. Estimated CTE non-cancer HQs also approached or exceeded 1 for all activities. In addition, estimated RME cancer risks also were at or above 1E-04 for most activities.

Although not included in the LA exposure estimates, as shown in **Table 7-4**, other types of asbestos (chrysotile, amosite, crocidolite, and anthophyllite) were also detected in several collected air samples (CDM Smith 2013j).

These results indicate that local tradesperson exposures have the potential to be significant if appropriate personal protective measures are not employed to mitigate exposures during active disturbances of indoor source materials. It is important to note that, even for properties that have had an interior removal or where no interior removal has been deemed necessary, there is the potential for tradesperson exposures to occur if source materials have been left in place (e.g., VI may be left if place if it is well-contained within walls [EPA 2003]). Although no tradesperson exposure data are available for properties in OU7, it is expected that the conclusions based on OU4 data would also apply to OU7.

7.3 Inside Schools in OU4

7.3.1 Exposure Parameters

There are two main receptor populations of interest for evaluating exposures inside schools – students and teachers. Because the student population differs by the type of school (i.e., younger children attend elementary school, older children attend high school), student exposure parameters were determined separately by school in OU4 and are based on information provided by school administrators. **Table 7-6** presents the selected exposure parameter values and calculated TWFs for indoor exposures at each school.

7.3.2 Investigation Summary

In December 2008, a study was conducted to evaluate indoor air concentrations of LA inside schools in OU4 (EPA 2008h). To minimize classroom disruption, samples were collected using stationary air monitors placed in multiple locations within each school building. Ten locations were selected per school building, generally including four classrooms, the lunch room/cafeteria, the gymnasium, and four hallways. To ensure that all samples were representative of average exposure conditions, each sample was collected over a period of two days. Sampling occurred only during the times that each location is typically used by students. That is, during extended periods when classroom or common areas (e.g., gymnasium, cafeteria) were vacant, sampling pumps were turned off until students returned. Hallways and other areas (e.g., library) that are used intermittently throughout the day were sampled for the entire school day. For each sampling location, the sampling cassette was placed at a level corresponding to the breathing zone of the students occupying the room. For example, in a classroom where students are usually seated at desks, the cassette was placed at the height of the face of a seated student. Conversely, in the gymnasium and hallways, the cassettes were placed at the height of a standing student. Detailed results of the indoor ABS at the OU4 schools are presented in (EPA 2010e).

Table 7-7 presents summary statistics of the measured TEM air concentrations by school. As shown, for several schools, all indoor ABS air samples collected were non-detect for PCME LA (mean achieved analytical sensitivity of about 0.0006 cc^{-1}). The mean air concentration (i.e., a concentration of zero) was used as the EPC in the risk calculations. The uncertainty assessment (Section 10) provides additional information on risk estimates for datasets where all samples are non-detect.

7.3.3 Risk Estimates

Table 7-8 presents the estimated cancer risks and non-cancer HQs for exposures to LA in indoor air in OU4 schools. As shown, these results indicate that, when these exposure scenarios are considered

alone, estimated cancer risks are below 1E-06 and non-cancer HQs are below 0.1 for all exposure scenarios inside OU4 schools. The contribution of these exposure scenarios to cumulative risk is discussed in Section 9.

7.4 Inside the Search and Rescue Building in OU1

As discussed previously, OU1 includes areas that were part of the former Export Plant (see **Figure 1-5**). The David S. Thompson Search and Rescue Building is the only building in OU1 that is regularly occupied. The Search and Rescue Building was constructed on the northwest portion of OU1 in 2004 (see **Figure 6-4**), and includes an office and a five-bay garage. The garage is used for storing search and rescue equipment and vehicles. Several other agencies, including local and state law enforcement, also hold meetings in the main office.

7.4.1 Exposure Populations and Parameters

Volunteer staff and individuals that attend meetings at the Search and Rescue Building may be exposed to LA in indoor air while inside the building. Exposure parameter data were obtained through a questionnaire administered in 2008 to individuals that use the building, including Search and Rescue volunteers. The detailed results of the survey are provided in **Appendix G**. **Table 7-9** presents the selected exposure parameter values and calculated TWFs for worker exposures inside the Search and Rescue Building in OU1.

7.4.2 Investigation Summary

An indoor ABS investigation was conducted inside the Search and Rescue Building in 2008. The results of this investigation were used in the *OU1 RI* (EPA 2009c) to evaluate potential risks to workers inside the Search and Rescue Building. At that time, it was concluded that risks from indoor exposures were within or below EPA's acceptable risk range (EPA 1991b). However, several additional remedial actions were conducted in OU1 since the indoor ABS investigation (CDM Smith 2013e). In accordance with the *OU1 ROD* (EPA 2010a), following implementation of the remedy, a post-construction risk assessment is needed to evaluate the effectiveness of the remedy for workers at the Search and Rescue Building. Thus, additional sampling data were deemed necessary to represent more recent conditions and evaluate post-ROD exposures.

Although there are no indoor ABS data that have been collected post-ROD inside the Search and Rescue Building, there are air clearance air samples that were collected in 2012 which provide data on indoor air concentrations of LA inside the building. In July 2012, a series of clearance air samples were collected in response to a citizen request. Clearance air samples were collected immediately following the use of a leaf blower inside the office and garage. The action of aggressively blowing dust from indoor surfaces effectively simulates a high-end exposure scenario. Following leaf blowing, fans were used to keep the air circulating and clearance air samples were collected using stationary air monitors. A total of five clearance air samples were collected; two samples from the office (meeting room and kitchen) and three samples from the garage. These samples were originally analyzed in 2012 and reported as non-detect (achieved analytical sensitivity of 0.009 cc^{-1}). The samples were re-analyzed in 2014 to achieve a better (lower) analytical sensitivity in support of their use in the risk assessment.

Table 7-10 (Panel A) presents summary statistics for the clearance air samples inside the Search and Rescue Building. The mean air concentration for each area (office, garage) was used as the EPC in the risk calculations.

7.4.3 Risk Estimates

Table 7-10 presents the estimated cancer risks and non-cancer HQs for exposures to LA inside the Search and Rescue Building in OU1 based on RME (Panel B) and CTE (Panel C). As shown, when this exposure scenario is considered alone, estimated RME and CTE cancer risks are below 1E-05 and non-cancer HQs are at or below 0.1 for both the office and garage under post-ROD conditions. These results support the risk conclusions of the earlier HHRA (EPA 2009c). The contribution of these exposure scenarios to cumulative risk is discussed in Section 9.

7.5 Inside Buildings in OU5

OU5 includes the former Stimson Lumber Mill and all properties owned by KBPID (see **Figure 1-5**). The majority of lumber production activities ceased in 2003, but there are still several buildings in OU5 (some vacant and some occupied) that are, or could be used in the future, for commercial/industrial purposes.

7.5.1 Exposure Populations and Parameters

The primary population of interest for the purposes of evaluating exposures inside OU5 buildings is commercial/industrial workers. Information on exposure parameters for indoor workers at OU5 was obtained through a questionnaire in the fall of 2007 for five of the eight occupied buildings at OU5. **Appendix G** summarizes the results of this survey. As shown, exposure information differed by building, with some buildings used frequently (e.g., the CDM Smith field office) and others used only occasionally (e.g., scale house). For vacant buildings where site-specific information on exposure was not available, exposure parameters were based on EPA default values for indoor workers.

Table 7-11 presents the selected exposure parameter values and calculated TWFs for worker exposures inside buildings in OU5.

7.5.2 Investigation Summary

In November/December 2007, EPA collected indoor ABS samples at 21 buildings in OU5 (CDM Smith 2007a). For the eight buildings that were occupied at the time of the study, an EPA contractor performed two types of indoor worker activity scenarios, including active behaviors (e.g., dust a desk or computer, sweeping or vacuuming a floor, walking from room to room) and passive behaviors (e.g., sitting at a desk working at a computer). Each activity was conducted for approximately two hours. For the 13 buildings that were vacant at the time of the study[21], five stationary air monitors were set up (one in the center of the building and one in each corner) and monitoring was performed following disturbance of the area with a leaf blower (i.e., a high-end active indoor disturbance scenario). Each stationary air sample was collected for a period of four hours following the disturbance.

Detailed results of the OU5 indoor ABS investigation are summarized in the *OU5 RI* (HDR 2013a). **Table 7-12** presents summary statistics of the measured TEM air concentrations for each building for each type of indoor disturbance activity. The mean air concentration for each building, stratified into active and passive behaviors, was used as the EPC in the risk calculations.

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[21] Since this ABS study, two vacant buildings originally sampled have either burned (plywood plant) or been demolished (log yard pump house). In addition, one vacant building (boundary injection building) that was within the OU5 boundary at the time is now outside the current boundary of OU5.

7.5.3 Risk Estimates

Table 7-13 presents the estimated cancer risks and non-cancer HQs for exposures to LA inside the buildings in OU5 based on RME (Panel A) and CTE (Panel B). As shown, with the exception of the Central Maintenance Building and the CDM Smith Libby field office (discussed below), estimated RME and CTE cancer risks are below 1E-05 and non-cancer HQs are below 1 for all buildings in OU5, when these indoor exposure scenarios are considered alone. The contribution of these exposure scenarios to cumulative risk is discussed in Section 9.

For the Central Maintenance Building, the RME non-cancer HQ is 1. Although an interior removal of VI was completed for at the Central Maintenance Building in 2005, residual indoor VI is known to remain in wall cavities (HDR 2013a). The RME non-cancer HQ is also 1 for the CDM Smith Libby field office based on indoor ABS data collected in 2007. However, subsequent ongoing indoor air monitoring of the CDM Smith Libby field office shows that, of the more than 350 indoor air samples collected since the ABS study, LA structures have been detected in only 9 samples, with an overall average PCME LA air concentration of 0.000063 s/cc (about 20 times lower than the "active" ABS air concentrations). This suggests that the 2007 indoor ABS dataset may be biased high relative to current exposure conditions. CTE cancer risks are below 1E-05 and non-cancer HQs are below 1 for both the Central Maintenance Building and the CDM Smith Libby field office.

7.6 Overall Risk Conclusions

In reviewing the risk calculation tables for indoor air exposures, there are a number of general conclusions that can be drawn:

- With the exception of indoor exposures at "pre-removal" residential/commercial properties and during tradesperson activities, estimated RME cancer risks are below 1E-04 and non-cancer HQs are at or below 1 for all indoor exposure scenarios.

- Residential and indoor worker exposures to LA have the potential to result in risks that are above a level of human health concern for properties where it has determined that an interior removal is necessary, but no removal has been performed ("pre-removal"). Estimated RME HQs are below 1 for properties where an interior removal has been completed ("post-removal") and where an interior removal is deemed not to be necessary ("no removal required"). These results demonstrate that interior property assessments have been effective at identifying when interior removals are not warranted and that interior removals, when performed, have been effective at mitigating sources of LA inside the property.

- Local tradesperson exposures have the potential to be significant and result in cancer risks above 1E-04 and non-cancer HQs above 1 (based on both RME and CTE) if appropriate personal protective measures are not employed to mitigate exposures during active disturbances of indoor source materials that contain LA. There is the potential for tradesperson exposures to occur, even for properties that have had an interior removal or where no interior removal has been deemed necessary, if source materials have been left in place (e.g., VI contained within walls).

Section 8

Risks from Exposures During Disturbances of Wood-Related Materials

Extensive data on LA levels on the bark surface of trees have been collected in the forested area near the mine (CDM Smith 2013a) and in the forested area near the current NPL boundary for the Site (CDM Smith 2013g). These data show that LA fibers are present on the outer bark surface of trees at the Site. Tree bark surface loading values of LA tend to be highest on trees closest to the mine (within about 3-4 miles), but LA was also detected on trees located even 13 miles from the mine (CDM Smith 2013g). LA has also been detected in other wood-related materials, including wood waste piles at Lincoln County landfills (Tetra Tech 2012c) and in woodchip/waste bark piles located in OU5 (CDM Smith 2007b,c).

If LA-containing trees or wood-related materials are disturbed, such as during wood harvesting activities or during gardening activities in landscaped areas covered by woodchips or mulch, people may become exposed to LA that is released to air from the wood. If LA-containing trees are used as a source of firewood (e.g., in a residential woodstove), studies have shown that LA fibers can become concentrated in the resulting ash (CDM Smith 2013k; Ward *et al.* 2009), which itself can become a source of potential LA exposure. Additionally, in the event of a wildfire, it is possible that LA may also be released to outdoor air when trees are burned in the fire. The various wood-related exposure media, exposure pathways, and exposure populations are illustrated in **Figure 2-1** and **Table 2-1**.

There have been several ABS investigations to evaluate LA concentrations in air during various wood-related disturbance scenarios. **Table 2-2** (Panel B) summarizes the types of wood-related ABS investigations that have been conducted. As shown, these studies provide measured data on LA concentrations in air during a variety of wood-related disturbance exposure scenarios. The studies that have been performed for each exposure scenario are summarized briefly below. The following sections summarize the exposure scenarios by which receptors may be exposed to LA during disturbances of wood-related materials, identify the exposure populations for each scenario, present the selected RME and CTE exposure parameter values and calculated TWFs for each scenario. These sections also summarize the results of studies performed at the Site to evaluate wood-related exposures, describe how these data are used to calculate exposures, and present estimated cancer risks and non-cancer HQs for each exposure scenario.

8.1 Exposure Scenarios

8.1.1 Residential Wood Harvesting

8.1.1.1 Exposure Populations and Parameters

Local area residents may harvest/collect firewood from forested areas within the NPL boundary for use in residential fireplaces and woodstoves. Residential wood harvesting activities may include sawing, hauling, and stacking wood for personal use. During these activities, residents may be exposed to LA when fibers are released to air from the surface of the tree bark. **Table 8-1** presents the selected RME and CTE exposure parameter values and calculated TWFs for evaluating potential exposures during residential wood harvesting activities.

8.1.1.2 Investigation Summary

Outdoor ABS was conducted in the summer of 2010 at three locations in the forested area downwind (northeast) of the mine site (EPA 2010f). The three ABS areas (ABS-10, ABS-07, ABS-02) were selected to represent locations at increasing distance from the mine site (i.e., approximately 2 miles [near], 4 miles [intermediate], and 8 miles [far] from the mine site) (see **Figure 6-7**). The ABS activities included felling trees with a chainsaw, de-limbing and cutting felled trees to length, and stacking harvested wood. Activities were performed by Grace's contractors in accordance with an EPA-developed SAP (EPA 2010f). A total of five sampling events were conducted in each ABS area between July and August 2010. Detailed results from this ABS study are presented in CDM Smith (2013a). **Table 8-2** (Panel A) presents summary statistics of the wood harvesting results for each ABS area. The mean air concentration for each ABS area was used as the EPC in the risk calculations.

8.1.2 Commercial Logging

8.1.2.1 Exposure Populations and Parameters

Workers who are employed in commercial logging operations may harvest wood from forested areas within the NPL boundary. Logging operations may include a variety of activities performed manually or by machinery, including felling, skidding, de-limbing, sawing, stacking, and milling timber. During these activities, workers may be exposed to LA when fibers are released to air from the surface of the tree bark. Additionally, commercial logging workers may also be exposed to LA due to soil/duff disturbances (e.g., while dragging logs across the ground or during site restoration activities). Because potential exposures likely differ depending upon the type of logging activity, and different workers may perform different jobs at a logging parcel, exposures are evaluated separately by job type. **Table 8-1** presents the selected RME and CTE exposure parameter values and calculated TWFs for evaluating potential exposures during commercial logging activities.

8.1.2.2 Investigation Summaries

In September of 2012, ABS was conducted to evaluate the potential exposures to outdoor workers during commercial logging activities near the mine in OU3 (EPA 2012b). The selected tree harvesting area was located approximately one mile downwind (northeast) of the mine site in a location where higher concentrations of LA had been reported in tree bark and duff in earlier studies (see **Figure 8-1**). The ABS activities included hand-felling of trees with a chainsaw, "hooking and skidding" felled trees to a central landing area, mechanical de-limbing and cutting of timber, and site restoration of the landing area using a bulldozer. In addition, it also included a wood chipping scenario to simulate potential exposures during timber milling activities. Detailed results from the 2012 commercial logging ABS study are presented in SRC, Inc. (2013b).

In September 2014, a second commercial logging ABS investigation (CDM Smith 2014k) was conducted in an area at a further distance from the mine, located approximately 4 miles downwind (northeast) of the mine site (see **Figure 8-1**). The ABS activities included the same types of commercial logging activities evaluated in 2012. Detailed results from the 2014 commercial logging ABS study are presented in CDM Smith (2014l).

Table 8-2 (Panel B) presents summary statistics of the commercial logging results for each type of logging activity for both the 2012 and 2014 investigations. The mean air concentration for each activity was used as the EPC in the risk calculations.

8.1.3 Wood Chipping

8.1.3.1 Exposure Populations and Parameters

Because local agencies have discouraged the burning of wood waste materials, wood waste generated from area residences and businesses has accumulated at the Lincoln County landfills. To reduce the volume of these wood waste piles, materials are regularly chipped. Because LA has been detected in the wood waste piles at both Lincoln County landfills (Tetra Tech 2012c), outdoor workers that perform these wood-chipping operations have the potential to be exposed to LA. **Table 8-1** presents the selected RME and CTE exposure parameter values and calculated TWFs for evaluating potential outdoor worker exposures during wood-chipping activities.

8.1.3.2 Investigation Summary

There have been two ABS studies conducted that provide information on potential exposures during wood-chipping activities. As discussed above (see Section 8.1.2), wood-chipping activities were conducted as part of the OU3 commercial logging study to simulate exposures during the milling process.

In addition, ABS was also performed in April of 2013 during wood-chipping of the wood waste pile at the Lincoln County landfill in Troy (OU7) (CDM Smith 2013l). This wood waste pile included both "raw" wood materials (e.g., large tree limbs, smaller branches and twigs, tree stumps) and manufactured wood materials (e.g., wood pallets, lumber, plywood). The ABS program included the collection of multiple personal air samples for the laborer operating the wood chipper, as well as the collection of stationary air samples for monitors located at varying distances downwind of the chipping activity. **Table 8-2** (Panel C) presents summary statistics of the wood-chipping results from the landfill. As shown, all ABS air samples collected as part of this sampling program were non-detect for PCME LA (mean achieved analytical sensitivity of 0.002 cc^{-1}). The mean air concentration (i.e., a concentration of zero) was used as the EPC in the risk calculations. The uncertainty assessment (Section 10) provides additional information on risk estimates for datasets where all samples were non-detect.

8.1.4 Forest Maintenance

8.1.4.1 Exposure Populations and Parameters

Outside of the Libby and Troy communities, most of the land within the current NPL boundary consists of forest, much of which is managed and maintained by USFS. USFS land management workers have the potential to be exposed to LA during forest maintenance activities. These activities may include tree stand examination and surveying, thinning vegetation and trimming trees, measuring trees, maintenance of roads and trails, etc. **Table 8-1** presents the selected RME and CTE exposure parameter values and calculated TWFs for evaluating potential exposures during forest maintenance activities.

8.1.4.2 Investigation Summary

In the summer of 2010, ABS was performed at three locations in the forested area downwind (northeast) of the mine site (EPA 2010f). The three ABS areas were co-located with the areas evaluated in the residential wood harvesting ABS study (see Section 8.1.1), and selected to represent locations at increasing distance from the mine site (see **Figure 6-7**). The ABS activities evaluated in this study were designed to simulate the types of activities routinely performed as part of the USFS land management worker responsibilities, including maintenance of roads and trails, thinning of trees and vegetation, and surveying trees. Activities were performed by Grace's contractors in accordance with an EPA-developed SAP (EPA 2010f). A total of five sampling events were conducted in each ABS

area between July and August 2010. Detailed results from this ABS study are presented in CDM Smith (2013a). **Table 8-2** (Panel D) presents summary statistics of the USFS forest maintenance results for each ABS area. The mean air concentration for each ABS area is used as the EPC in the risk calculations. The uncertainty assessment (Section 10) provides additional information on risk estimates for datasets where all samples are non-detect.

8.1.5 Wood Chip/Mulch Disturbances

8.1.5.1 Exposure Populations and Parameters

Several woodchip and waste bark piles were left at OU5 from historical lumber processing activities. As noted above, sampling and analysis of these piles has shown LA is present in these wood materials. Woodchips from these piles have been sold and given away for use as landscaping mulch in gardens, flowerbeds, playgrounds, etc. There are two populations that were selected for the purposes of evaluating potential exposures to LA during woodchip/mulch disturbance activities – outdoor workers that disturb the piles in OU5 during occupational activities and residents that disturb woodchip/mulch landscaping materials. **Table 8-1** presents the selected RME and CTE exposure parameter values and calculated TWFs for evaluating potential exposures during woodchip/mulch disturbance activities.

8.1.5.2 Investigation Summary

In October of 2007, test pit excavations were performed at the woodchip and waste bark piles in OU5 to investigate whether disturbances of these piles was of potential concern to outdoor workers (CDM Smith 2007b). Excavations consisted of digging a pit into the side of the pile with an excavator (i.e., back hoe). Personal ABS air samples were collected for the excavator operator and the sampling personnel during the waste bark and woodchip pile test pit excavations.

In August of 2011, ABS was conducted to provide data on LA concentrations in air during woodchip disturbances, simulating activities that might be performed by a gardener (CDM Smith 2012b). During this ABS study, woodchips were collected from each of the two piles in OU5 and these materials were used to conduct ABS. The ABS activities included digging in the woodchips, using both a long shovel and a trowel, and raking the woodchips. Three sampling events were performed for each of five sets of collected woodchip materials.

Table 8-2 (Panel E) presents summary statistics of results for each woodchip disturbance investigation. All ABS air samples collected as part of these two sampling programs were non-detect for PCME LA. The mean air concentration (i.e., a concentration of zero) was used as the EPC in the risk calculations. The uncertainty assessment (Section 10) provides additional information on risk estimates for datasets where all samples are non-detect.

8.6.1 Ash Disturbances

8.6.1.1 Exposure Populations and Parameters

Trial burn experiments in woodstoves (Ward *et al.* 2009) and in test burn chambers (EPA 2012c) indicate that the majority of LA structures are retained in the ash when wood and duff materials are burned. Because the LA becomes concentrated in ash, this has the potential to be an important source media for LA exposures. If LA-containing firewood is burned in a residential woodstove, residents may be exposed to LA that is released to air from the resulting ash during removal of ash from the woodstove. **Table 8-1** presents the selected RME and CTE exposure parameter values and calculated TWFs for evaluating potential exposures during woodstove ash disturbance activities.

8.1.6.2 Investigation Summary

In 2012, EPA conducted an ABS study to measure LA concentrations in air during woodstove ash-removal activities (CDM Smith 2012f). For this study, firewood was collected from dead trees at three locations at varying distances from the mine site (see **Figure 8-2**) – near the mine (approximately one mile downwind of the mine site), intermediate from the mine (near Flower Creek, approximately 2 miles south of Libby), and far from the mine (near Bear Creek, approximately 10 miles south of Libby and outside the current NPL boundary). The firewood collected from each location was burned in a woodstove (tree bark was not removed prior to burning). The resulting ash was removed from the woodstove using a long-handled metal shovel and placed into a metal ash bucket (similar to what might be done by a resident). Detailed results from this ABS study are presented in CDM Smith (2013k). **Table 8-2** (Panel F) presents summary statistics of the measured ABS air concentrations for each firewood collection location. The mean air concentration for each location was used as the EPC in the risk calculations.

8.1.7 Wildfires

8.1.7.1 Exposure Populations and Parameters

A wildfire that occurs in an area of the forest where the trees and duff contain LA could result in the release of LA fibers into air, which has the potential to expose people to LA in areas near and downwind of the fire. There are two populations of interest for the purposes of evaluating LA exposures during wildfires – local residents and responding firefighters. Depending upon the size of the fire and location, there may be both ground-based and air-based responding firefighters. Because potential exposures likely differ for each, firefighter exposures are evaluated separately for ground-based and air-based responders. **Table 8-1** presents the selected RME and CTE exposure parameters values and calculated TWFs for evaluating potential residential and firefighter exposures during wildfires.

8.1.7.2 Investigation Summary

In the event of an authentic wildfire that is in or near the current NPL boundary, there are sampling plans in place at the Site (EPA 2013; CDM Smith 2013m) to collect opportunistic air samples, both at stationary monitors throughout the Libby community and near the wildfire (to evaluate exposures to firefighters). To date, air samples have only been collected during one wildfire event.

In late July 2013, a small (1.5 acre) wildfire occurred in the Souse Gulch day-use recreation area on Lake Koocanusa behind Libby Dam (approximately 2.5 miles southeast from the mine). During this fire, air samples were collected to provide data on LA exposures of responding firefighters (both to the ground crews and the aircraft support pilot) and downwind LA concentrations in air during the fire. **Table 8-2** (Panel G) presents summary statistics of the measured air concentrations for each sample type collected. The mean air concentration for each sample type was used as the EPC in the risk calculations.

No measured data are available on potential airborne concentrations of LA during wildfires that may occur closer to the mine. EPA has used modeling to estimate potential LA exposures to firefighters near the mine during a wildfire response (EPA 2012d) based on LA release rates from duff obtained during a burn chamber study (EPA 2012c). These data have not been included in this HHRA, but screening level results are presented and discussed in EPA (2012d). In brief, this report concluded that estimated exposures of firefighters from LA in smoke might exceed the OSHA worker limits for short periods of time under "worst case" or high-end exposure conditions, but typical exposures are likely to be within OSHA limits (EPA 2012d).

8.2 Risk Estimates

Table 8-3 presents the estimated cancer risks and non-cancer HQs for exposures to LA during disturbances of wood-related materials based on RME (Panel A) and CTE (Panel B). These results indicate that, when these exposure scenarios are considered alone, RME and CTE cancer risks are below 1E-04 and non-cancer HQs are below 1 for most exposure scenarios. Non-cancer HQs for commercial logging activities and woodstove ash disturbance activities are at or above 1 based on RME. The following subsections provide a detailed discussion of estimated risks from commercial logging and woodstove ash disturbance activities.

8.2.1 Risks from Commercial Logging

When commercial logging activities were conducted near the mine in an area with high concentrations of LA in bark and duff, non-cancer HQs are above 1 for skidding/hooking activities and site restoration activities (see **Table 8-3**). However, estimated RME and CTE cancer risks are below 1E-05 and non-cancer HQs are below 1 when commercial logging activities were performed in 2014 further from the mine (i.e., where bark and duff LA levels were lower).

In reviewing the commercial logging ABS results near the mine, there are several general observations. First, LA concentrations in air during tree-felling tended to be lower than other logging activities and similar to measured ABS air concentrations during residential wood harvesting (see Panel A of **Table 8-2**). Second, air concentrations during hooking/skidding and site restoration activities, which included both disturbances of wood as well as soil and duff materials, tended to be about an order of magnitude higher than during felling activities, which was primarily a bark disturbance scenario (i.e., limited soil/duff disturbances). These data suggest that disturbances of soil/duff may be more important sources of LA exposure to commercial logging workers than tree bark.

8.2.2 Risks from Ash Disturbances

Non-cancer HQs associated with the removal of ash from a woodstove differed depending on the source of the firewood that was burned (see **Table 8-3**). If firewood was collected from a location near the mine, where tree bark LA levels are highest, the RME HQ for LA exposures during ash removal activities is 1. However, if firewood was collected from a location intermediate or far from the mine, RME HQs are below 0.1.

These risk estimates demonstrate that ash may be an important source medium, especially if the ash is derived from a wood source in close proximity to the mine. The LA present in the ash is likely to be derived from fibers on the outer bark surface; however, there are no data that provide information on differences in LA content of outer bark and “inner” wood. There are also no data on potential LA exposures from ash disturbances when the source firewood has had the outer bark removed prior to burning.

Although risk estimates were calculated for one type of ash disturbance scenario, there are several other potential ash disturbance scenarios for which measured ABS air data are not available, including residential exposures to ash in outdoor fire pits or recreational visitor exposures to ash from campfires. There are also no ABS air data that provide information on potential residential exposures if LA-containing ash is disposed in gardens or flowerbeds.

Additionally, ash resulting from a wildfire event may also be an important source medium. As noted above, burn tests show that the majority of LA structures are retained in the ash when wood and duff materials are burned. Analyses of ash collected from the Souse Gulch wildfire burn area showed LA

concentrations of about 50 million structures per gram of ash (Ms/g), which is similar to concentrations measured in woodstove ash after burning firewood collected near the mine (CDM Smith 2013k). However, there are no measured ABS air data to provide information on exposures to LA from ash disturbances within the burn area following a wildfire.

Section 9

Evaluation of Cumulative Risk

Most people who live or work in Libby or Troy are likely to be exposed to LA by a combination of the exposure scenarios described and evaluated separately in Section 5 through Section 8. Consequently, it is important to estimate the total (cumulative) risk to a receptor who is exposed by multiple scenarios over their lifetime. The calculation of cumulative risk is complicated by the fact that the exposure pattern of each individual at the Site may be unique. However, EPA does not typically perform risk calculations for specific individuals, but rather for generic classes of receptor populations with common exposure patterns. Thus, the goal of the cumulative risk assessment is to characterize how cumulative risk depends on different types of disturbance activities, LA levels in the source media, and exposure locations.

9.1 Basic Approach

Cumulative risk from LA is expressed as the sum of the risks across various types of exposure scenarios, calculated as follows:

$$\text{Cumulative Cancer Risk} = \left(\sum EPC_s \cdot TWF_s\right) \cdot IUR_{LA}$$

$$\text{Cumulative Non-Cancer HI} = \left(\sum EPC_s \cdot TWF_s\right) / RfC_{LA}$$

where:

EPC_s = Exposure point concentration for exposure scenario ‘s’ (PCME LA s/cc)

TWF_s = Time-weighting factor for exposure scenario ‘s’

IUR_{LA} = LA-specific inhalation unit risk $(\text{PCM f/cc})^{-1}$

RfC_{LA} = LA-specific reference concentration (PCM f/cc)

These equations help emphasize a basic principle – the risk from any one exposure scenario depends both on the exposure concentration in air (which depends on the concentration in the source medium and on the nature of the disturbance), and on the frequency and duration of the exposure (reflected in the TWF term). While high exposure concentrations tend to increase risk, a high exposure concentration alone will not necessarily result in excess risk if the TWF is small. Conversely, while lower exposure concentrations tend to decrease risk, a low concentration may not necessarily result in low risk if the TWF is large. Rather, both exposure concentration (EPC) and exposure time (TWF) influence the risk equally. Likewise, the relative risk contributed by any one scenario depends on both EPC and TWF, and cannot be inferred from either one alone.

In summing across multiple exposure pathways, it is important to note that the underlying exposure assumptions, which form the basis of the risk estimates, do not yield a cumulative TWF that is greater than 1.0. This is because the value of each scenario-specific TWF term describes the fraction of a lifetime during which asbestos exposure occurs for that scenario. Consequently, the sum of the TWF terms across all exposure scenarios may not exceed 1.0 (100% of a lifetime). In other words, the total

number of hours of asbestos exposure cannot be greater than the total number of hours in a lifetime, which is assumed to be 70 years (i.e., 24 hours/day · 365 days/year · 70 years = 613,200 hours).

To illustrate this, suppose the cumulative exposure for a receptor includes the following six exposure pathways:

1. Outdoor air in OU4 under ambient conditions
2. Outdoor air while fishing along the Kootenai River
3. Indoor air in a OU4 residential property during active behaviors
4. Indoor air in a OU4 residential property during passive behaviors
5. Outdoor air at an OU4 residential property during yard work
6. Indoor air in the Central Maintenance Building in OU5

If the RME TWF values used in the previous risk calculations were selected for use in the cumulative assessment, the cumulative TWF across these six exposure pathways would be greater than 1.0:

Exposure Pathway	RME TWF_s (Source)	Hours of exposure in a lifetime*
A-Outdoor air, OU4, ambient conditions	0.20 (Table 5-3)	122,640
B-Outdoor air, OU3, fishing along Kootenai River	0.039 (Table 6-15)	23,915
C-Indoor air, OU4, residential property, active	0.17 (Table 7-1)	104,244
D-Indoor air, OU4, residential property, passive	0.48 (Table 7-1)	294,336
E-Outdoor air, OU4, residential property, yard work	0.032 (Table 6-1)	19,622
F-Indoor air, OU5, Central Maintenance Building	0.11 (Table 7-11)	67,452
Cumulative:	**1.031**	**632,209**

*Calculated as RME TWF_s · 613,200 hours

Typically, RME estimates are based on a 95th percentile estimate (or another high-end statistic) of a population for any activity. The cumulative impact of adding a series of 95th percentile estimates will result in a total exposure that is higher than physically possible. *Therefore, cumulative risk for various combinations of exposure scenarios cannot be calculated simply by summing the estimated risks presented in Section 5 through Section 8 without checking to be sure the total TWF does not exceed 1.0.*

Instead, exposure-specific TWF values for use in the cumulative assessment must be selected by specifying the fraction of the lifetime spent engaging in each exposure scenario, taking care to ensure that the cumulative TWF is equal to 1.0. This approach is illustrated in **Figure 9-1**. In this example, the cumulative exposure scenario includes the same set of six exposure pathways described above, but the TWF values have been adjusted to ensure that the total number of hours of asbestos exposure does not exceed a 70-year lifetime of 613,200 hours (i.e., the cumulative TWF sums to 1.0).

TWF values for each exposure pathway used in the cumulative assessment were selected based primarily on professional judgment, taking into consideration the specified RME and CTE exposure parameters for each exposure pathway. In general, RME values were selected for a few of the exposure pathways and the remaining pathways were selected to be more characteristic of CTE values.

9.2 Cumulative Risk Estimates

There are essentially an infinite number of possible exposure scenario combinations that could be evaluated in the cumulative risk assessment for the Site. The choice of which combinations to evaluate is a matter of judgment. For the purposes of this risk assessment, four alternate cumulative exposure scenario combinations were selected for evaluation. These were chosen to characterize the wide range of potential cumulative risks that may occur and to help identify which exposure scenarios tend to be the most substantial contributors to total risk. A detailed description of the cumulative exposure scenarios for each receptor example is provided in Section 9.2.1. Several additional cumulative examples are provided in Section 9.2.2 to illustrate how cumulative risk changes as a function of LA levels in source materials, interior removal status, and receptor behaviors.

9.2.1 Selected Cumulative Exposure Scenarios

The following sections describe the cumulative exposure scenarios for each of four receptor examples; showing the selected TWF for each exposure pathway and presenting graphical illustrations of the cumulative TWF and non-cancer HI. **Figures 9-2 to 9-5** present graphical illustrations of the cumulative assessment for each receptor example, respectively. In these figures, the upper panel illustrates the contribution of each exposure pathway to the total fraction of a lifetime as a pie chart, where the full pie represents the 613,200 hours that encompass a 70-year lifetime. The lower panel illustrates the contribution of each exposure pathway to the cumulative HI as a stacked bar graph. The table below the figures provides a tabular presentation of the information shown in the two figures. (Note: These figures only present cumulative HIs as the non-cancer endpoint appears to be the more sensitive metric of potential risk. The fractional contribution of each exposure pathway to total cancer risk is the same as for the non-cancer HI.)

9.2.1.1 Receptor Example #1

Example #1 illustrates the potential cumulative exposure and risk to a receptor that lives in Libby at residence where a curb-to-curb soil removal has been completed (i.e., a full yard soil removal was performed) and an interior removal effort has been completed (i.e., a "post-removal" residence). **Figure 9-2a** illustrates this "baseline" residential exposure, meaning the exposure is attributed only to those pathways associated with the residential property (i.e., ambient air, indoor air inside the residence, and outdoor air within residential property line). As illustrated in **Figure 9-2a**, the "baseline" residential exposure scenario yields a cumulative HI less than 1; the cumulative cancer risk is also below 1E-05 (i.e., within EPA's acceptable risk range). However, this cumulative exposure scenario does not account for potential exposures outside the residential property. Thus, this cumulative exposure scenario was made more realistic by adding in additional pathways outside the residence.

In addition to the "baseline" residential exposure, the following exposure pathways were added:

- This receptor attends school (elementary through high school) in Libby.
- This receptor works in a commercial building in Libby where an interior removal effort was deemed not to be necessary (i.e., conditions inside the building did not trigger an interior removal).
- This receptor drives on roads in Libby.

- This receptor also engages in a variety of recreational activities, such as bicycling in OU4, motorcycle riding at the MotoX Park in OU5, ATV riding in LUAs where soil concentrations are Bin A (non-detect), hiking in the forested areas far (>8 miles) from the mine site, fishing along the Kootenai River, and playing disc golf at the course in Troy (OU7).
- The majority (90%) of the lifetime of this receptor is spent at the Site (i.e., 10% of the lifetime is spent offsite).

This exposure scenario is likely to represent a "low-end" cumulative exposure scenario, since potential exposures tend to occur at properties and locations with lower levels of LA, and this receptor does not engage in activities that would be expected to increase potential LA exposures (e.g., disturbances of soils with detected LA or disturbances of LA-containing VI).

As illustrated in **Figure 9-2b**, even after adding in multiple exposure pathways to the "baseline" residential exposure, the cumulative exposure scenario for Receptor Example #1 yields a cumulative HI less than 1; the cumulative cancer risk is also within EPA's acceptable risk range. This example shows that receptors who are predominantly exposed at properties and in locations where steps have been taken to limit potential exposures to LA (e.g., exterior and interior removals have been completed or deemed not to be necessary), even when the cumulative scenario includes many different exposure activities across multiple OUs, are likely to have cumulative risks that are below a level of concern.

9.2.1.2 Receptor Example #2

Example #2 illustrates the potential cumulative exposure and risk to a receptor that lives in Libby at a residence where yard soil concentrations are Bin B2 and an interior removal effort is deemed necessary, but has not yet been completed (i.e., a "pre-removal" residential property). This receptor also works in a commercial building in Libby at which an interior removal effort is deemed necessary, but has not yet been completed (i.e., a "pre-removal" commercial property). This receptor engages in a variety of outdoor activities, such as hiking along Rainy Creek in OU3, riding ATVs along ROWs in OU8, and harvesting firewood from the forested areas near (<4 miles) the mine (OU3). In addition, this receptor burns the firewood that was harvested in a woodstove, and is exposed to LA during ash removal activities. The majority (90%) of the lifetime of this receptor is spent at the Site.

This exposure scenario is likely to represent a "high-end" exposure scenario, as the exposure scenarios selected for inclusion all tend to occur at properties and locations with higher levels of expected LA, and this receptor tends to engage in multiple activities that would be expected to increase potential LA exposures.

As illustrated in **Figure 9-3**, the cumulative exposure scenario for Receptor Example #2 yields a cumulative HI that is well above 1; cumulative cancer risks are also above 1E-04. This example shows that cumulative exposures have the potential to become significant if the majority of the receptor lifetime is spent at properties and in locations where LA is present and engaging in source disturbance activities that have a high potential for LA releases.

This example also illustrates that those exposure pathways which contribute most to the total lifetime exposure time do not necessarily contribute most to the cumulative HI. For example, exposure from ambient air (exposure scenario "A") comprises 15% of the total lifetime exposure time (TWF_S of 0.15), but contributes only 0.1% to the cumulative HI. Conversely, some exposure pathways that contribute a small amount to the total lifetime exposure time contribute significantly to the cumulative HI. For

example, exposure during disturbances of residential yard soil (exposure scenarios “D” and “E”) contributes about 5% to the total lifetime exposure time (TWF_s of 0.05), but comprises 50% of the cumulative HI.

9.2.1.3 Receptor Example #3

Example #3 illustrates the potential cumulative exposure and risk to a receptor that lives in Libby at a residence where yard soil concentrations are non-detect for LA (i.e., Bin A) and an interior removal effort has been completed (i.e., a “post-removal” residential property). This receptor works in a commercial building in Libby at which an interior removal effort was deemed not to be necessary (i.e., conditions inside the building did not trigger an interior removal) and at the Central Maintenance Building in OU5. This receptor participates in a variety of outdoor activities, such as hiking in forested areas at an intermediate (4-8 miles) distance from the mine, bicycling on paths in OU5, and playing in parks in Troy (OU7). The majority (90%) of the lifetime of this receptor is spent at the Site.

The cumulative exposure scenario for Receptor Example #3 is presented in **Figure 9-4**. As shown, although the HQ values for each individual exposure scenario are less than 1, the cumulative HI is above 1. This example illustrates the importance of evaluating potential exposure scenarios as part of a cumulative assessment and not just individually. However, calculations based on individual exposure scenarios provide useful information on potential “risk drivers” that can be used to guide risk managers in determining future remedial levels and/or institutional controls. (A “risk driver” is an individual exposure pathway that contributes a substantial fraction of the cumulative risk.)

It is important to note that a cumulative HI above 1 does not necessarily mean that adverse non-cancer effects will occur. As noted previously (see Section 3.3.2), there is a margin of safety built into the RfC, as the derivation of the RfC_{LA} included a UF of 300 (EPA 2014c). Thus, a cumulative HI that only moderately exceeds 1 has a relatively small likelihood of actually causing an adverse effect. However, the probability of an adverse effect tends to increase as the cumulative HI increases.

9.2.1.5 Receptor Example #4

Example #4 illustrates the potential cumulative exposure and risk to a receptor that lives in Libby at a residence where a curb-to-curb yard soil removal has been performed and an interior removal effort has been completed (i.e., a “post-removal” residential property). This receptor participates in recreational activities in OU3, including hiking and building/burning campfires near the mine site. This receptor has also had several types of worker exposures over the course of a lifetime, including working in a commercial building in Libby at which an interior removal effort was deemed not to be necessary (i.e., conditions inside the building did not trigger an interior removal), working as a commercial logger (felling/skidding timber) in forested areas near the mine site (OU3), and working as a USFS worker performing various forest maintenance and firefighting activities in the forested areas in OU3. The majority (90%) of the lifetime of this receptor is spent at the Site.

As illustrated in **Figure 9-5**, the cumulative exposure scenario for Receptor Example #4 yields a cumulative HI that is above 1. This example demonstrates that, even though the total time spent in OU3 (exposure scenarios “G” to “M”) contributes only about 8% to the total lifetime exposure time, these exposures contribute nearly 75% of the cumulative HI. Additionally, about 70% of the cumulative HI is due to a single exposure scenario, performing skidding as part of commercial logging operations near the mine (exposure scenario “K”). The TWF_s for this individual exposure scenario is 0.002, which is the equivalent of working as a skidder for approximately two summers for 8 hours per day, 5 days per week, for 15 weeks per summer. This example illustrates that, if commercial logging

operations are performed near the mine, these activities have the potential to contribute significantly to the cumulative HI of the person doing the logging, even when the exposure time is limited. This example also illustrates that, with the exception of the skidding scenario, exposures from occupational and recreational activities in OU3 contribute less to the cumulative HI than exposures in OU4.

9.2.2 Changing Cumulative Risk

As noted above, the following examples are provided to specifically illustrate how cumulative risk changes as a function of LA levels in source materials, interior removal status, and receptor behaviors.

9.2.2.1 LA Levels in Source Materials

It is important to understand that the cumulative HI depends not only on which exposure pathways are included, but also on the nature of the source materials where those exposures occur. Soil disturbance activities performed in a yard where LA is non-detect (Bin A) by PLM-VE will contribute less risk than the same type of activities performed in a yard where LA soil concentrations are reported as 1% (PLM-VE Bin C). **Figure 9-6** illustrates the importance of LA concentration in soil to the cumulative HI. In this example, the exposure scenarios are identical (i.e., the TWF pie chart is unchanged), but the EPC utilized in the risk calculation has been adjusted from representing a Bin C yard soil concentration to a Bin A concentration. As shown, the cumulative HI decreases from 10 to 1 when the yard soil that is disturbed is changed from 1% (Bin C) to non-detect (Bin A).

The same is true for potential exposures from indoor air during woodstove ash removal activities and from commercial logging activities. **Figure 9-7** (Panel A) presents a cumulative HI example that includes exposures from woodstove ash. This figure illustrates the cumulative HI if the ash is derived from firewood collected near the mine site and far from the mine site. In this example, the exposure scenario is identical; only the source of the firewood used in the woodstove is different. As shown, the cumulative HI decreases from 2 to 0.9 when the firewood source is changed from near the mine to far from the mine. **Figure 9-7** (Panel B) illustrates the cumulative HI if commercial logging activities (felling, skidding trees) are conducted near the mine site (within one mile) and intermediate from the mine site (about 4 miles from the mine). As shown, the cumulative HI decreases from 4 to 0.8 when the commercial logging location is changed to be further from the mine.

These examples demonstrate how cumulative exposures and risks can decrease, without altering activity behavior patterns, by lowering LA levels in source media where disturbance activities are performed (e.g., removing yard soils with 1% LA and replacing with non-detect soil) and/or by changing the locations where these disturbance activities are performed (e.g., collecting firewood and performing logging in areas further from the mine site versus near the mine site).

9.2.2.2 Interior Removal Status

The same is also true for indoor exposure scenarios; it is possible to change cumulative exposures and risks, without altering activity behavior patterns, by addressing LA source materials inside properties.

Figure 9-8 illustrates how the cumulative HI decreases when indoor residential and workplace exposures occur at properties where LA-containing indoor source materials have not been addressed ("pre-removal") to properties where these materials have been addressed ("post-removal") or where no removal has been deemed necessary ("no removal required"). In this example, the exposure scenario is identical; only the type of property is different. As shown, indoor air exposures have the potential to contribute significantly to cumulative exposures and risks if the majority of time is spent inside residences and workplaces where a removal has been deemed necessary, but has not been

performed. However, the cumulative HI is reduced from 4 to 0.6 once these indoor sources have been addressed.

Currently, there are three criteria that are evaluated to determine the need for an interior removal (EPA 2003):

1) The presence of open, uncontained, or migrating VI in attics/walls

2) The presence of VV in the indoor living space (e.g., VI that has migrated from the attic or walls into the main living spaces)

3) Measured indoor dust levels above 5,000 total LA structures per square centimeter (s/cm^2)

As illustrated in **Figure 9-8,** these criteria are effective in determining when interior removals are not needed, as evidenced by the fact that cumulative HIs are generally similar for exposures at "post-removal" (0.6) and "no removal required" (0.7) properties.

9.2.2.3 Addressing Risk Drivers

As noted above, of the numerous exposure pathways that may be included in the cumulative assessment, those exposure pathways where LA-contaminated source materials are disturbed tend to be important risk drivers in cumulative HI estimates.

As illustrated in **Figure 9-9**, for this exposure scenario, two exposure pathways contribute more than half of the cumulative HI for this example receptor – hiking along lower Rainy Creek near the mine site and disturbing VI during tradesperson demolition activities. **Figure 9-9** demonstrates how elimination of these two risk drivers affects the cumulative HI. As shown, if this receptor were to hike along the Kootenai River (in OU2), instead of along lower Rainy Creek (in OU3), the cumulative HI is reduced from 3 to 2. If this receptor were to also utilize personal protective equipment (e.g., respirator) and employ appropriate dust mitigation measures while performing VI-disturbing activities, which would effectively change the EPC to zero, the cumulative HI is reduced to 1.

This example demonstrates that it is not necessary to address every single exposure pathway to significantly lower the cumulative risks. Addressing exposures for a small subset of the potential exposure pathways, focusing on risk drivers, will have the greatest impact in lowering cumulative exposures and risks. In this regard, the cancer risk and non-cancer HQ summary tables presented in Section 5 through Section 8 provide useful information on the individual exposure pathways that have the potential to be important cumulative risk drivers.

9.3 Cumulative Risk Conclusions

In reviewing these cumulative HI examples, several general conclusions can be made:

- Cumulative HI estimates are below 1 if exposures tend to occur at properties and locations with lower levels of LA. However, cumulative HI estimates have the potential to be well above 1 if exposures occur at properties and locations with higher levels of expected LA.

- When cumulative exposure includes exposure pathways where LA-contaminated source materials are disturbed, such as hiking along lower Rainy Creek near the mine site, performing timber skidding operations near the mine site, or disturbing VI during tradesperson activities, these pathways are important risk drivers for cumulative HI estimates.

- Those exposure pathways that contribute most to the total lifetime exposure time do not necessarily contribute most to the cumulative HI. In some cases, exposure pathways that contribute little to the total lifetime exposure time can contribute significantly to the cumulative HI.
- It is possible to reduce cumulative exposure and risk, without altering activity behavior patterns, by lowering LA levels in source media where disturbance activities are performed (e.g., removing yard soil with LA) and/or by changing the locations where the activities are performed (e.g., collecting firewood from areas far from the mine site).
- It is not necessary to address every single exposure pathway to significantly lower cumulative HIs. Addressing exposures for risk drivers will have the greatest impact in lowering cumulative exposures and risks.
- It is possible for individual exposure pathway HQs to be below 1, but the cumulative HI across all exposure pathways to be above 1. Thus, risk managers should consider both cumulative risks and individual exposure pathway risks to identify potential risk drivers to guide decisions on future remedial levels and/or institutional controls.

Section 10
Uncertainty Assessment

As with all HHRAs, uncertainties exist due to limitations in the exposure and toxicity assessments and our ability to accurately determine cumulative exposure and risk from multiple sources over a lifetime. This risk assessment has used the best available science to evaluate potential human health exposures and risks from LA at the Site. However, there are number of sources of uncertainty that affect the risk estimates that must be considered when making risk management decisions. The most important of these uncertainties are discussed below.

Because of these uncertainties, the cancer risks and non-cancer HQs for individual exposure scenarios are uncertain, and consequently all estimates of cumulative cancer risks and non-cancer HI values presented in this HHRA are also uncertain, and should be considered to be approximate. Actual risks may be either higher or lower than estimated.

10.1 Exposure Assessment Uncertainties

10.1.1 Uncertainty in True Long-Term Average LA Concentrations in Air

Concentrations of LA in air (especially ABS air) are inherently variable, so estimates of mean exposure concentrations are subject to uncertainty arising from random variation between individual samples ("sampling uncertainty"). The magnitude of the uncertainty due to sampling variability depends on the number of samples collected and the variability between individual samples, with uncertainty tending to decrease as sample number increases, and increasing as between-sample variability increases. In general, large data sets (e.g., with 10-20 or more samples) are likely to capture most of the effect of sampling uncertainty, while data sets that are substantially smaller will be more uncertain.

This sampling uncertainty is further compounded by the effect of analytical measurement error. If it were possible to actually examine the entire air filter by TEM, it would be possible to count exactly the number of LA structures present on the filter and the true concentration in the air that passed through the filter would be known with certainty. However, due to time and cost constraints, the TEM analysis examines only a small portion of the total filter. For example, a typical ABS air filter has an area of about 385 mm^2, yet a TEM analysis of 100 grid openings will only examine about 1 mm^2 (only about 0.25% of the total filter area). For the purposes of reporting the air concentration for the sample, it is assumed to be equal to the concentration as determined based on the small portion of the filter area examined.

For each air filter analyzed, the number of asbestos structures observed during the analysis is a random variable that is characterized by the Poisson distribution:

$$Count_{observed} \sim POISSON(\lambda)$$

where:

$Count_{observed}$ = Number of asbestos structures observed during the analysis

λ = Expected average count, calculated as:

$$\text{Concentration}_{\text{true}}\ (\text{s/cc}) \cdot \text{Volume of Air Analyzed (cc)}$$

For example, if λ were 3.72 structures, then the probability of observing a specified number of structure counts during the TEM analysis is shown in **Table 10-1** (Panel A). This is referred to as Poisson uncertainty. The magnitude of Poisson uncertainty depends mainly on the number of asbestos structures counted during the analysis. In general, the relative magnitude of the uncertainty due to Poisson variation tends to be largest for small structure counts, and decreases as count increases (see **Appendix B** for details). This concept is illustrated in **Figure 10-1**. As shown, above about 25 structures, there is little change in the relative uncertainty.

The 90% confidence interval around a count of *N* structures is given by:

$$LB = \tfrac{1}{2} \cdot CHIINV[0.05, 2N+1]$$

$$UB = \tfrac{1}{2} \cdot CHIINV[0.95, 2N+1]$$

where:

LB = Lower bound count on the 90% confidence interval on *N*

UB = Upper bound count on the 90% confidence interval on *N*

CHIINV = Inverse Chi-squared cumulative distribution function

N = Number of asbestos structures observed

Two examples of this calculation are shown in **Table 10-1** (Panel B).

The overall uncertainty in a measured concentration is the combination of the sampling uncertainty and the Poisson uncertainty, depending in a very complex way on the number of samples collected, between-sample variability, number of structures counted, and volume of air passing through the area of filter examined. In risk assessments for non-asbestos contaminants, EPA recommends that risk calculations be based on the 95UCL of the sample mean to minimize the chances of underestimating the true level of exposure and risk (EPA 1992). However, at present, there is no EPA-approved method for calculating the 95UCL for asbestos datasets, which adequately accounts for both sampling and Poisson uncertainty. Therefore, in accordance with EPA guidance (EPA 2008a), all risk calculations presented in the risk characterization (Section 5 through Section 9) utilize the sample mean. The sample mean is an unbiased estimate of the true concentration (see **Appendix B**), but the true concentration may be either higher or lower.

10.1.2 Uncertainty in the EPC Due to Non-Detects

When calculating the EPC, the sample mean is computed simply by averaging the concentrations across all samples, treating "non-detects" (samples with a count of zero) as having a concentration of zero (EPA 2008a). For the purposes of this discussion, this EPC is referred to as the "best estimate" of the mean (BE). However, as the number of non-detects in a data set becomes large, the uncertainty (due to Poisson uncertainty) around the BE tends to increase. Therefore, in order to provide information on the magnitude of the Poisson uncertainty, risk estimates were evaluated for several datasets using an alternate EPC metric.

This alternate EPC metric is determined by assuming the concentration of each non-detect is equal to 1 PCME structure times the achieved analytical sensitivity of that sample, and then computing the mean across all samples. For example, if the achieved analytical sensitivity for a non-detect sample were 0.001 cc^{-1}, the concentration for that sample would be evaluated as 0.001 PCME LA s/cc, rather than zero. Although not statistically rigorous, assuming the data set contains an adequate number of samples to capture sampling variability, this alternate EPC metric may reasonably be thought of as an "upper-bound" on the mean (UB). As illustrated in **Figure 10-2**, when a dataset has a high frequency of detects, the UB will approach the BE; but when a dataset has a low frequency of detects, the UB will approach the mean achieved sensitivity. Use of the UB in calculating risk estimates is considered to be conservative, especially when many or all of the samples in a dataset are non-detect.

Appendix H summarizes the estimated cancer risks and non-cancer HQs (based on RME) for each dataset using the UB. **Table 10-2** presents several examples of the UB risk calculations. As shown, for those datasets where the LA detection frequency was high (e.g., **Table 10-2**, Panel A, exposures during disturbances of yard soils with Bin B2/C concentrations of LA), estimated risks based on the UB are similar or equal to those based on the BE. Even for many datasets where all samples were non-detect (e.g., **Table 10-2**, Panel B, exposures during disturbances of soils in OU2) or LA detection frequency was low, use of the UB does not alter overall risk conclusions (i.e., cancer risk estimates and non-cancer HQs are below a level of concern regardless of the EPC metric). This is because the target analytical sensitivity requirements were specified such that the target sensitivity was lower than a scenario-specific risk-based level of potential concern.

For a few datasets (**Table 10-2**, Panel C), such as hiking in the forest or driving on roads in OU3, estimated non-cancer HQs exceed 1 based on the UB, but do not based on the BE. For these datasets, the achieved analytical sensitivity was not adequate to support decisions based on the non-cancer endpoint. Typically, this occurs in earlier (pre-2011) ABS datasets. This is because earlier ABS programs were conducted prior to the development of the RFC_{LA} and target analytical sensitivity requirements were derived to be protective of the cancer endpoint (which is not the most sensitive endpoint). It is possible to improve (lower) the achieved analytical sensitivity by performing a supplemental TEM analysis (i.e., examine additional grid openings) for the previously collected air filters that are in the project archive. As noted previously, supplemental analyses have been performed for several ABS air datasets (e.g., see Section 6.1.2 and 6.2.2). Thus, it is possible to reduce the level of uncertainty in these datasets through additional analysis if necessary to support risk management decision-making.

10.1.3 Uncertainty Due to Air Filter Preparation Methods

As discussed in Section 2.3.4, collected air filters are examined at the laboratory prior to analysis to determine the estimated particulate loading on the filter. If an air filter is not deemed to be overloaded by particulates and there is no loose material in the cowl, the filter is directly prepared for analysis by TEM. If an air filter is deemed to be overloaded or if loose material is noted in the air cassette or adhering to the cowl, the filter is prepared indirectly (usually with ashing) in accordance with the indirect filter preparation procedures in Site-specific SOP EPA-LIBBY-08. For chrysotile asbestos, indirect preparation tends to increase structure counts due to dispersion of bundles and clusters; however, the effects of indirect preparation on amphibole asbestos are generally much smaller, usually only increasing concentrations by a factor of 2-3 (Berry *et al.* 2014; Goldade and O'Brien 2014).

In order to ensure that air concentrations used in the risk assessment were not biased high due to filter preparation methods, concentrations for all air samples that were indirectly prepared were adjusted (decreased) by a factor of 2.5. This factor was based on Libby-specific studies of the potential effect of indirect preparation on air samples (Berry *et al.* 2014). However, the actual effect of indirect preparation will likely depend upon the nature of the LA structures present on the filter, which could differ depending upon the source material (e.g., soil, tree bark, VI), the sampling location (e.g., at the mine site in OU3, inside an attic at an OU4 residence), and the type of disturbance activity. Hence, the estimated air concentration calculated using an adjustment factor of 2.5 may be higher of lower than the true concentration.

A further source of uncertainty is between-laboratory variations in the determination of which filters require indirect preparation. This is because the decision to use an indirect preparation is inherently subjective. Laboratories with a lower tolerance for loose/adhering materials will tend to perform indirect preparations more frequently, and these results would require adjustment (as described above) to account for potential high bias due to indirect preparation methods. Laboratories with a higher tolerance for loose/adhering materials will tend to perform a direct preparation, even when it is possible that an indirect preparation may have been warranted. In this case, results may be biased low because the preparation did not include potential asbestos structures that may have been present in the loose/adhered materials. It is not possible to quantify the potential bias or adjust concentrations due to differences in filter preparation method preferences between TEM laboratories.

10.1.4 Uncertainty Due to Analytical Methods

As discussed in Section 6.1.6.3, unlike traditional chemistry methods, where analytical results are based solely on the output of a laboratory instrument, analytical results for asbestos are dependent upon subjective analyst interpretations. Thus, high data quality is ensured through the use of laboratories and analysts that are well-trained in asbestos analysis, and specifically trained in the analysis of LA.

All analytical laboratories participating in the analysis of samples for the Site are accredited by the National Institute of Standards and Technology (NIST) National Voluntary Laboratory Accreditation Program (NVLAP) for the analysis of asbestos by TEM and/or PLM. This accreditation process includes the analysis of NIST/NVLAP standard reference materials, or other verified quantitative standards, and successful participation in two rounds of proficiency testing per year each of bulk asbestos by PLM and airborne asbestos by TEM as supplied by NIST/NVLAP. In addition, each laboratory working for the Site is also required to pass an onsite EPA laboratory audit, participate in ongoing analytical discussions with other project laboratories, and meet Site-specific data reporting requirements.

Even with these quality assurance (QA) procedures, due to the subjective nature of both TEM and PLM analyses, results can differ between analysts and laboratories. Because of this, the analytical QC program for the Site performs regular evaluations of both within- and between-laboratory variability in asbestos results for both analytical methods. A detailed evaluation of the QA procedures and QC analysis results is presented in CDM Smith (2012c, 2014d) and summarized in **Appendix D**. The following sections summarize some of the method-specific uncertainties of the data utilized in the risk assessment.

10.1.4.1 TEM

When analyzing an air filter for asbestos, the TEM analyst visually scans prepared grids for potential asbestos fibers. When a structure is observed, the distinction between asbestos/non-asbestos and asbestos type (e.g., chrysotile, actinolite, amosite) is determined based on a visual assessment of the structure-specific selective area electron diffraction (SAED) pattern and energy dispersive spectra (EDS) spectra, comparing them to a spectral library of known asbestos types. Interpretation of the EDS spectra with respect to LA determination requires significant training, as LA is inclusive of a range of asbestos mineral types (EPA 2008i). EDS interpretation is further complicated by the fact that spectra can differ between TEM instruments, chemical composition can differ within an asbestos structure (e.g., the EDS obtained at the end of a fiber may differ from the EDS at the center point of the same fiber), and spectra can be influenced by surrounding matrix particles.

Results of the TEM laboratory QC analyses show that there are differences in structure counting and recording methods within and between the analytical laboratories, with within-laboratory precision being better than between-laboratory (CDM Smith 2012c, 2014d). Grid opening re-examination (recount) results show there were some differences noted in the number of LA structures counted and in the differentiation of LA structures from non-asbestos material structures with EDS that are similar to LA (e.g., pyroxene). Yet, despite these differences, the number of LA structures counted usually only differed by one structure. For air samples, the between-laboratory differences in structure counting and recording methods are not likely to be a large source of uncertainty in reported air concentrations.

10.1.4.2 PLM

For the purposes of most exposure pathways evaluated in the risk assessment, uncertainties in the PLM method are not likely to alter risk management decisions, because soil data were not considered in the risk characterization. However, for other exposure pathways (e.g., residential properties in OU4 and OU7 without measured outdoor ABS data during soil disturbances), potential risks were extrapolated based on LA soil concentrations as determined by PLM-VE.

Most of the PLM methods currently available for the analysis of asbestos in solid media were developed for the analysis of building materials containing relatively high asbestos levels and are not generally intended for assessing low-level (<1%) asbestos contamination in soil. Indeed, even the Site-specific PLM-VE method is not able to reliably detect the levels of LA in soil below about 0.2% by mass (EPA 2008j). When performing a PLM-VE analysis, the analyst utilizes visual estimation techniques (e.g., standard area projections, photographs, drawings, or trained experience) to estimate the LA content of the soil and results are reported semi-quantitatively based on visual comparisons to LA-specific reference materials. The “detection limit”[22] is dependent upon the ability of the analyst, but is typically about 0.2% to 0.3% LA (by mass) (EPA 2008j). This means that soil LA concentrations below about 0.2%, may not be reliably identified by PLM-VE, and some soils ranked as Bin A (non-detect) by PLM-VE likely contain low levels of LA that cannot be reliably quantified. Thus, the difference between Bin A (non-detect) and Bin B1 (trace LA present at concentrations less than 0.2%) is not always distinct. As such, result reproducibility is especially difficult for Bin A and Bin B1. Because risk conclusions differ for exposures to yard soils that are Bin A versus Bin B1 (see **Table 6-3a** and **Table 6-3b**), the distinction between these two bins is important.

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[22] For this discussion, the “detection limit” is defined as the concentration that must be present in a sample such that the method will be able to detect LA 95% of the time.

Although within-laboratory reproducibility is generally good for PLM-VE, inter-laboratory results show that there are differences between the analytical laboratories (CB&I 2012; CDM Smith 2012c, 2014d). In particular, the ESATR8 laboratory has demonstrated proficiency in detecting the presence of “trace” levels (Bin B1) of LA in soil compared to other laboratories (CDM Smith 2014d). In general, the majority of soil samples used to group the outdoor ABS air data were analyzed by the ESATR8 laboratory. Thus, there is less uncertainty in the PLM-VE results for samples used in the risk assessment. However, the ESATR8 laboratory did not begin performing PLM-VE analyses until about 2008; thus, soil samples collected prior to this would have been analyzed by non-ESATR8 laboratories. Any extrapolation of the risk characterization results to OU4 and OU7 properties without outdoor ABS must consider which PLM laboratory performed the soil analyses. Even for PLM analyses performed by the ESATR8 laboratory, all soil sample results are uncertain due to the inherent variability in the analytical method.

10.1.5 Uncertainty Due to Field Collection Methods

10.1.5.1 Air

There have been few changes to the basic air sampling methodology at the Site. A known volume of air is drawn through a filter that is inside an air sampling cassette which is either affixed to a stationary monitor, such as is done for the collection of ambient air samples, or to an individual, such as during the various ABS programs. While the sampling durations, pump flow rates, and ABS scripts varied depending upon the objectives of the investigation, the underlying air sample collection methods remain consistent. Even so, measurements of LA in air, especially under source disturbance conditions, are inherently variable. For example, measured outdoor ABS air concentrations during disturbances of yard soils ranked as Bin B1 (trace) span more than four orders of magnitude (EPA 2010d). This is not unexpected since the release of LA from soil to air can depend not only on LA concentration, but also upon multiple other factors, such as soil moisture content, vegetation coverage and condition, humidity, and intensity of the disturbance activity. This is not an inherent limitation of the ABS methodology; in fact, it is desirable for the collected data to span the range of air concentrations that may result during source disturbances under a variety of conditions, such that the resulting EPCs are representative of long-term exposures.

Recognizing the variability in asbestos air concentrations, the air sampling programs employed at the Site typically included multiple sampling events at each sampling location to better capture the range of sampling variability due to changing environmental and meteorological conditions. As noted previously, more than 3,100 ABS air samples and 1,500 ambient air samples have been collected at the Site. These datasets provide the most comprehensive evaluation of airborne asbestos exposures ever collected at an asbestos-contaminated Superfund site.

10.1.5.2 Soil

As noted previously in Section 6.1.6.3, soil sampling methodologies at the Site have changed over time. Prior to 2007, soil samples collected at the Site were usually collected as five-point composite samples. The number of samples collected at the property varied, depending upon the types of use areas identified (e.g., yards, driveways) and the size of the use area. In 2007, the sampling methodology was changed to collect 30-point composite samples and the property evaluation methods were revised to better characterize each potential use area (CDM Smith 2013n). Because a 30-point composite is more likely to provide an accurate representation of the true average

concentration in soil over a study area than a five-point composite, soil concentration estimates based on five-point composites are more uncertain than those based on 30-point composites.

Recognizing this limitation, EPA has determined that properties evaluated prior to 2007 where no removal was conducted and where previously collected soil samples show detected LA is present (Bin B1, Bin B2) will be re-evaluated using current sampling protocols (CDM Smith 2014m). EPA is also conducting a pilot study to determine if a re-evaluation is necessary for properties evaluated prior to 2007 where no removal was conducted and where previously collected soil samples show no detected LA is present (Bin A) (EPA 2014f).

10.1.6 Uncertainty in Human Exposure Patterns

10.1.6.1 Differences Between Individuals

For every exposure pathway of potential concern, it is expected that there will be differences between different individuals in the level of exposure due to differences in exposure time, exposure frequency, and exposure duration. Thus, there is normally a wide range of average daily exposures between different individuals of an exposed population. In this risk assessment, two types of exposures are estimated – CTE, which represents "average" exposures, and RME, which represents exposures near the upper end of the range. The true exposure for any individual within a given population may be either higher or lower than the exposure parameters selected in the risk assessment, so risks to individuals may vary from the values presented in this report. In accordance with EPA (1991b), risk managers generally focus on RME risk estimates for the purposes of supporting risk management decision-making, which ensures that decisions are sufficiently protective of the general population.

10.1.6.2 Exposure Parameter Assumptions

Risk calculations require knowledge of the exposure time, duration, and frequency for a variety of exposure scenarios. However, limited or no Site-specific data were available on these exposure parameters; thus, exposure parameters for each receptor population and exposure scenario were selected based mainly on professional judgment, taking into consideration EPA default values and Site-specific factors. For example, EPA's RME default value for residential exposure frequency is 350 days/year (EPA 1993). The exposure frequency for residential exposures to LA during driveway soil disturbances was adjusted to 225 days/year to reflect Site conditions and account for days when releases due to soil disturbance activities were unlikely, either due to snow cover or high soil moisture content (from November through March) (see **Table 6-1**).

In some cases, exposure data were assumed based on professional judgment. For example, there is no information available on the fraction of yard soil disturbance time that is spent in "high-intensity" disturbance activities. For the purposes of this risk assessment, it was assumed that 5% of the total yard disturbance time is spent performing high-intensity disturbance activities (see Section 6.1.4.1.1). **Table 10-3** illustrates the change in estimated residential RME cancer risks and non-cancer HQs from yard soil disturbances if this assumption were changed from 5% (Panel A) to 20% (Panel B). As shown, although the absolute risk values increase, there is no change in the overall risk conclusions for this exposure pathway. Even if the assumed fraction of time spent in high-intensity disturbances were 20%, estimated RME cancer risks are below 1E-04 and non-cancer HQs are below 1 for soils where LA is not detected (Bin A) and above a level of potential concern for soils where LA is detected (Bin B1, Bin B2/C). Indeed, even if it were assumed that 70% of the yard disturbance time were spent in high-intensity disturbances (calculations not shown), the estimated RME cancer risks and non-cancer HQs would continue to be below a level of potential concern for Bin A (non-detect) soil concentrations.

In general, when exposure data were limited or absent, exposure parameters were chosen in a way that was intended to be conservative. Therefore, the values selected are thought to be more likely to overestimate than underestimate actual exposure and risk.

10.2 Toxicity Assessment Uncertainties

The toxicity factors for LA (IUR_{LA}, RfC_{LA}) are derived from the best available epidemiological studies in humans (EPA 2014c). However, there are a number of sources of uncertainty inherent in these values, including the following:

- *Uncertainty in exposure estimates.* Estimates of worker exposure to LA are based on a limited set of industrial hygiene measures performed in the workplace. Because there is variability between locations and over time, these measurements may or may not fully capture the true exposure levels in the workplace. In addition, because the measurements are generally based on stationary monitors, rather than personal monitors, the exposures experienced by individual workers may differ from those captured by the stationary monitors. Finally, each worker has a unique job history, and variations due to days off, sick time, shifts in job duties, etc., may or may not be fully captured in the calculations.

- *Uncertainty in exposure-response relationships.* As described in EPA (2014c), there is uncertainty in the best exposure-response model to use to describe both cancer and non-cancer effects in workers. This includes both the mathematical form of the models, as well as the best set of explanatory variables. In both cases (cancer and non-cancer), EPA investigated a range of alternative models and exposure matrices, and selected the combination that is judged to be most reliable. Although model choice can yield different values, as demonstrated in EPA (2014c), all models evaluated resulted in RfC_{LA} values that were within one order of magnitude.

- *Uncertainty in Age-Dependence.* Exposure-response models developed previously by EPA for evaluating cancer risks from inhalation of asbestos indicated that cancer risk depended on the age at first exposure as well as the duration of exposure (EPA 1986). That is, predicted cancer risk from a specified exposure concentration and duration (e.g., 0.001 f/cc for 10 years) is highest when exposure occurs early in life and tends to decrease as age at first exposure increases. For this reason, EPA (2008a) developed a table of IUR values applicable to a wide range of differing age at first exposures and exposure durations. In contrast, neither the LA-specific IUR nor the RfC were developed using models where age at first exposure was an explanatory variable. If age at first exposure does influence the risk of adverse effect, then the toxicity factors for LA might tend to underestimate risks from exposure scenarios that occur early in life. EPA (2014c) includes a review of studies that provide information on the age-dependence of the adverse effects of LA, and finds that the data are too limited to draw strong conclusions.

- *Statistical uncertainty in model fit.* Given the preferred model and exposure metrics for cancer and non-cancer effects, there is statistical uncertainty in the best fit of the model to the epidemiological data. To account for this, EPA derived toxicity factors not only based on the best fit, but also factors that characterizes the upper-bound on the toxicity per unit exposure. These conservative estimates of the toxicity factors were used in the derivation of the IUR_{LA} and RfC_{LA}, which helps ensure that risks are more likely to be overestimated than underestimated.

- *Database Uncertainty.* In the derivation of the RfC_{LA}, a composite UF of 300 was applied to account for data deficiencies in the available health effects literature (UF = 3), human variability and potentially susceptible individuals (UF = 10), and a data-informed subchronic-to-chronic factor to address uncertainty due to increasing risk of LPT over the course of a lifetime (UF = 10) (EPA 2014c).

In summary, the quantitative toxicity values for LA are derived in a way that is intended to be conservative, and are more likely to overestimate than underestimate true risks.

10.3 Cumulative Risk Characterization Uncertainties

Individuals that reside, work, or visit the Site will have exposures to LA from numerous potential source materials, locations, and activities. It is not possible to evaluate every possible cumulative exposure scenario combination. In addition, TWF values for each exposure pathway used in the cumulative assessment were selected based primarily on professional judgment, setting some exposure pathways to high-end values and others to more typical values.

The cumulative risk assessment presents estimated exposure and risks for a limited number of examples, with the goal of demonstrating the range of potential risks that could be present at the Site, as well as how risk depends on different types of disturbance activities, LA levels in the source media, and exposure locations to guide future risk management decision-making.

Section 11

Risk Assessment Conclusions

This Site-wide risk assessment characterizes risks to people from exposure to LA at the Site to help risk managers determine if past removal actions have been sufficient to mitigate risk, if additional remedial actions are necessary to address risks, and if so, which exposure pathways would need to be addressed in future remedial actions. Results of this risk assessment are intended to help inform Site managers and the public about the magnitude of potential risks attributable to LA and to guide the selection of final remedial actions for the Site.

The primary exposure pathway of concern for LA is inhalation. This risk assessment evaluates risks from potential inhalation exposures to LA in outdoor ambient air, in outdoor air during soil disturbance activities, in indoor air (under both active and passive disturbance activities), and air during wood-related disturbance activities. Because people may be exposed by multiple exposure scenarios, often across multiple OUs, potential cumulative exposures and risks were evaluated on a Site-wide basis for a wide range of multi-activity exposure scenarios. The risk assessment conclusions based on the exposure scenario-specific risk estimates and the cumulative risk estimates are discussed below.

11.1 Exposure Scenario-Specific Risks

In total, more than 150 different exposure scenarios were evaluated in the risk assessment in Section 5 through Section 8. The RME and CTE non-cancer HQs for every exposure scenario evaluated in the risk assessment are depicted in **Figures 11-1 to 11-4**. Note that these figures only depict non-cancer HQs and not cancer risks, because non-cancer hazard is the more sensitive metric of potential health risk. **Figure 11-1** presents HQs for exposures to outdoor ambient air, **Figure 11-2** presents HQs for exposures to outdoor air during soil disturbance activities, **Figure 11-3** presents HQs for exposures to indoor air (under both active and passive disturbance activities), and **Figure 11-4** presents HQs for exposures to air during wood-related disturbance activities. As seen, there were very few exposure scenarios that, when considered alone, yield RME non-cancer HQs that exceed 1. These exposure scenarios include (listed from highest to lowest HQ below):

- Tradesperson exposures during active source disturbance activities, such as VI removal or demolition, inside residential and commercial properties in Libby and Troy
- Outdoor worker exposures during disturbances of subsurface soils with LA contamination (Bin B2/C)
- Residential and outdoor worker exposures during disturbances of surface soils with detectable LA concentrations (e.g., Bin B2/C)
- Outdoor worker exposures during commercial logging activities in OU3 near the mine (within about one mile), especially those logging activities that disturb soil and duff material (e.g., skidding)

- Residential and indoor commercial worker exposures to indoor air during active source disturbance activities inside properties where one or more interior removal triggers are present (i.e., at "pre-removal" properties)

- Recreational visitor exposures while hiking along Rainy Creek in OU3

In addition to the above exposure scenarios, although quantitative risk estimates were not calculated, it is expected that non-cancer HQs also have the potential to be above a level of concern for trespassers or "rockhounds" in the disturbed mine area in OU3 or if individuals disturb subsurface soils in OU1 and OU2 where LA contamination has been left at depth following soil remediation.

11.2 Cumulative Risk

The calculation of cumulative risk is complicated by the fact that the exposure pattern of each individual at the Site may be unique. However, EPA does not typically perform risk calculations for specific individuals, but rather for generic classes of receptor populations with common exposure patterns. Thus, the goal of the cumulative risk assessment is to illustrate how risk depends on different types of disturbance activities, LA levels in the source media, and exposure locations. The cumulative risk calculations demonstrate:

- People who are predominantly exposed at properties and in locations where steps have been taken to limit potential exposures to LA (e.g., exterior soil removals and interior VI removal and cleanings have been completed or deemed not to be necessary), are likely to have cumulative risks that are below a level of concern, even when the cumulative scenario includes many different exposure activities across multiple OUs.

- Cumulative exposure has the potential to become significant if the majority of the receptor lifetime is spent at properties and in locations where LA is present and engaging in source disturbance activities that have a high potential for LA releases.

- When cumulative exposure includes scenarios where LA-contaminated source materials are disturbed, such as hiking along lower Rainy Creek near the mine site, disturbing surface soils with Bin B2/C concentrations, performing commercial logging operations near the mine site, disturbing VI during tradesperson activities, or disturbing subsurface soils with residual LA contamination, these exposures are important risk drivers for cumulative risk estimates.

- Addressing exposures for the risk drivers (i.e., those exposure scenarios that have HQs that approach or exceed 1), will have the greatest impact in lowering cumulative exposures and risks.

Section 12

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FIGURES

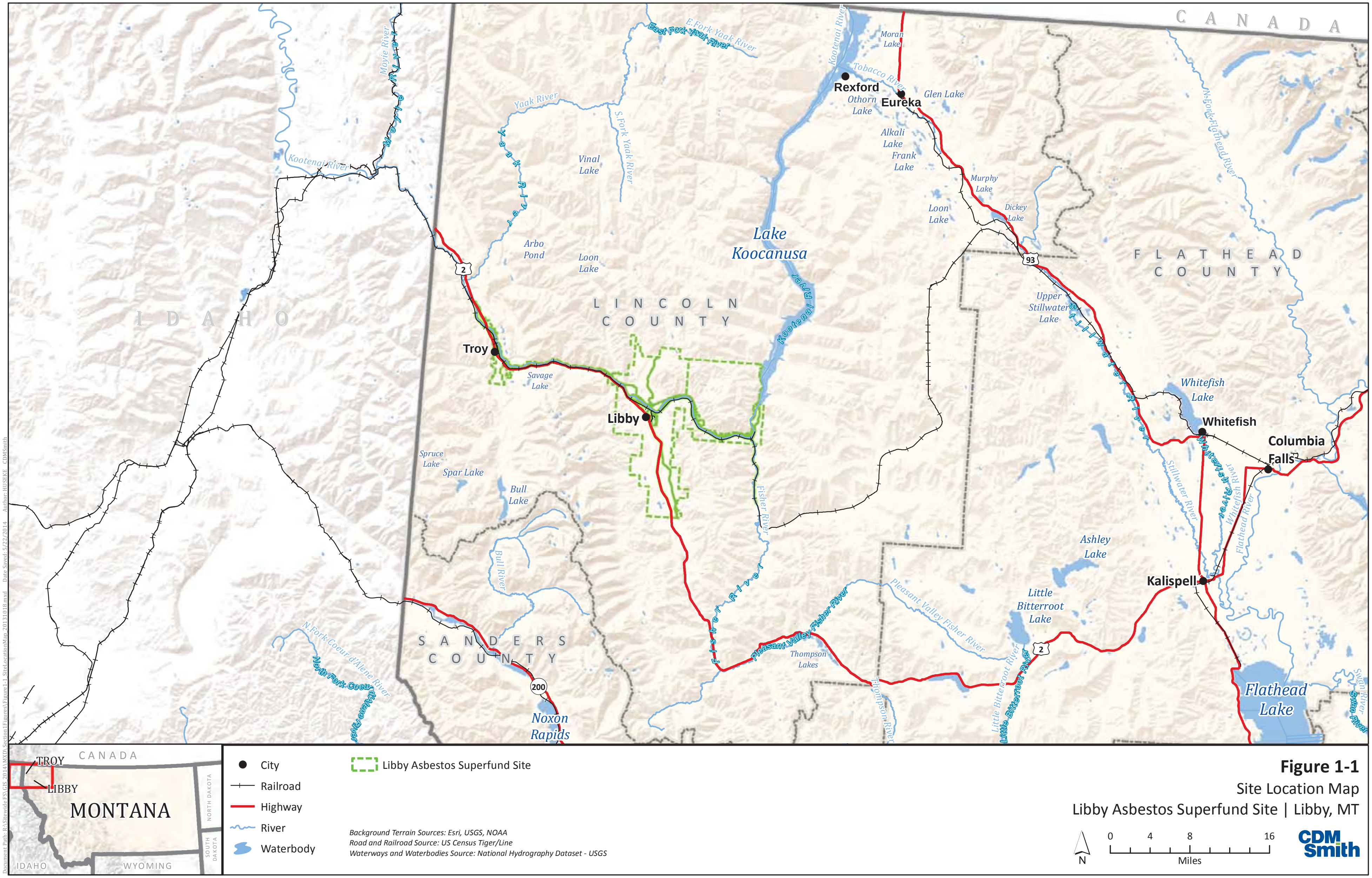


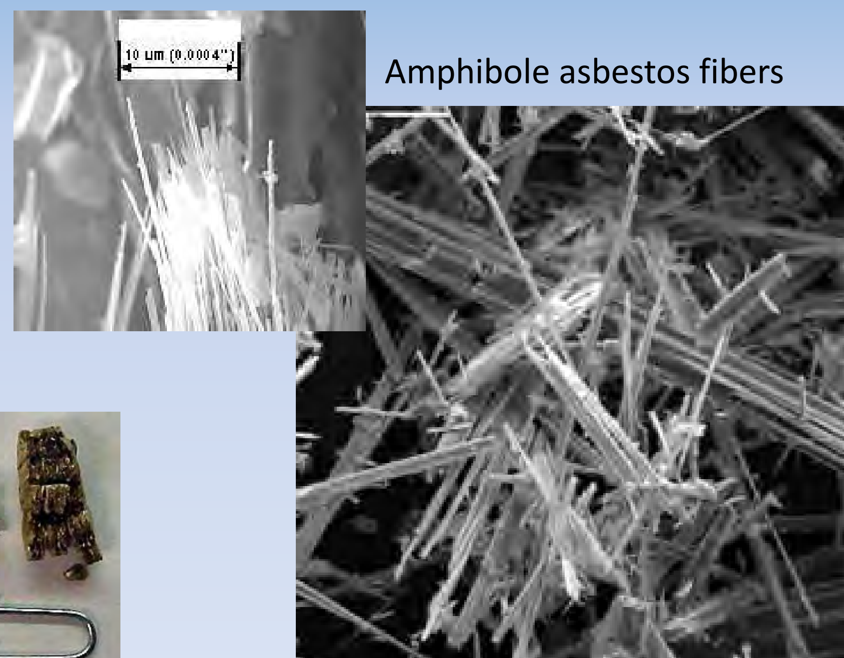
Figure 1-1
Site Location Map
Libby Asbestos Superfund Site | Libby, MT

Vermiculite ore

Unexpanded (“unexfoliated”) vermiculite

Expanded (“exfoliated”) vermiculite

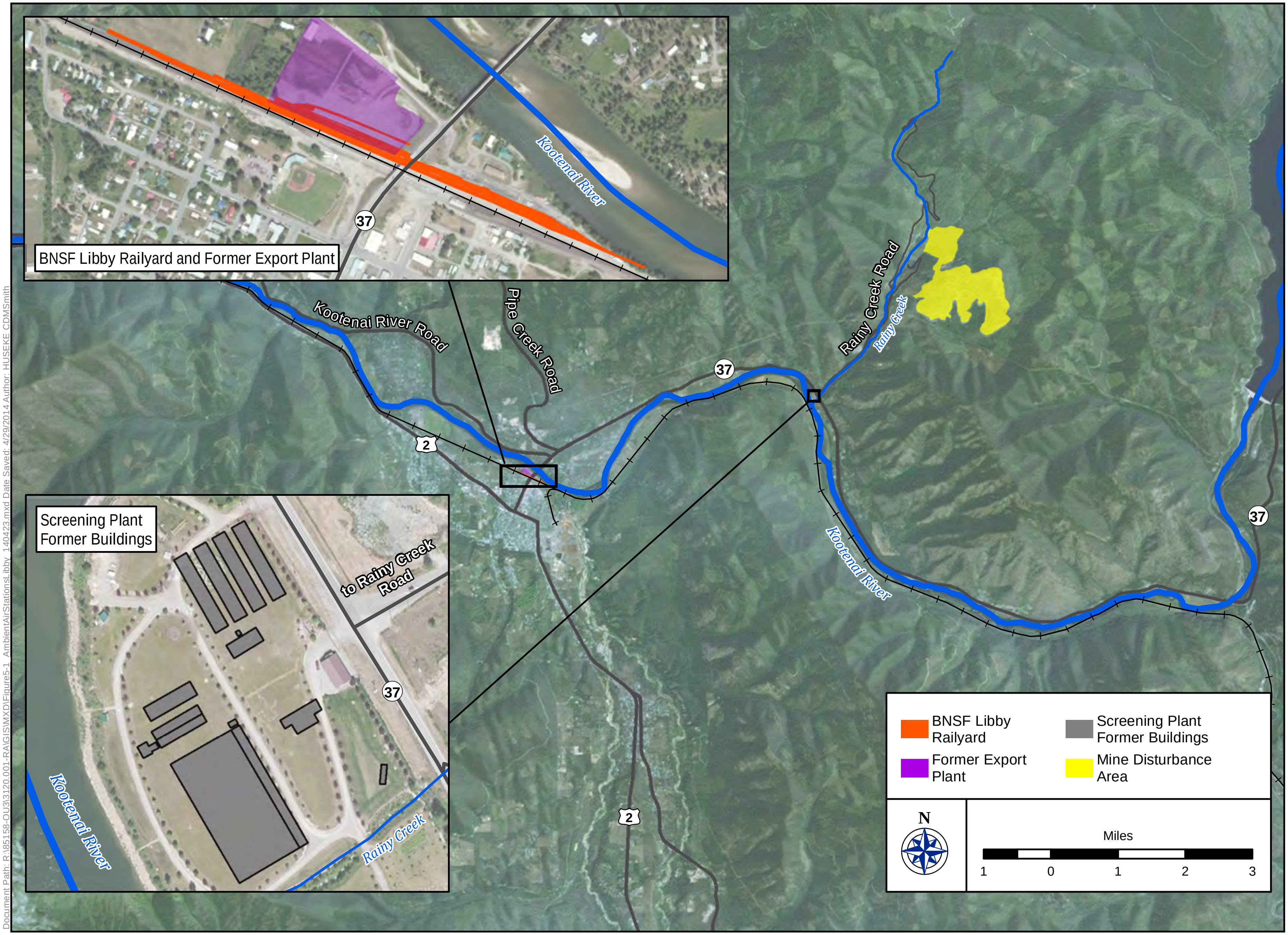
Zonolite products



Amphibole asbestos fibers

Figure 1-2. Photographs of Vermiculite and Asbestos

Libby Asbestos Superfund Site



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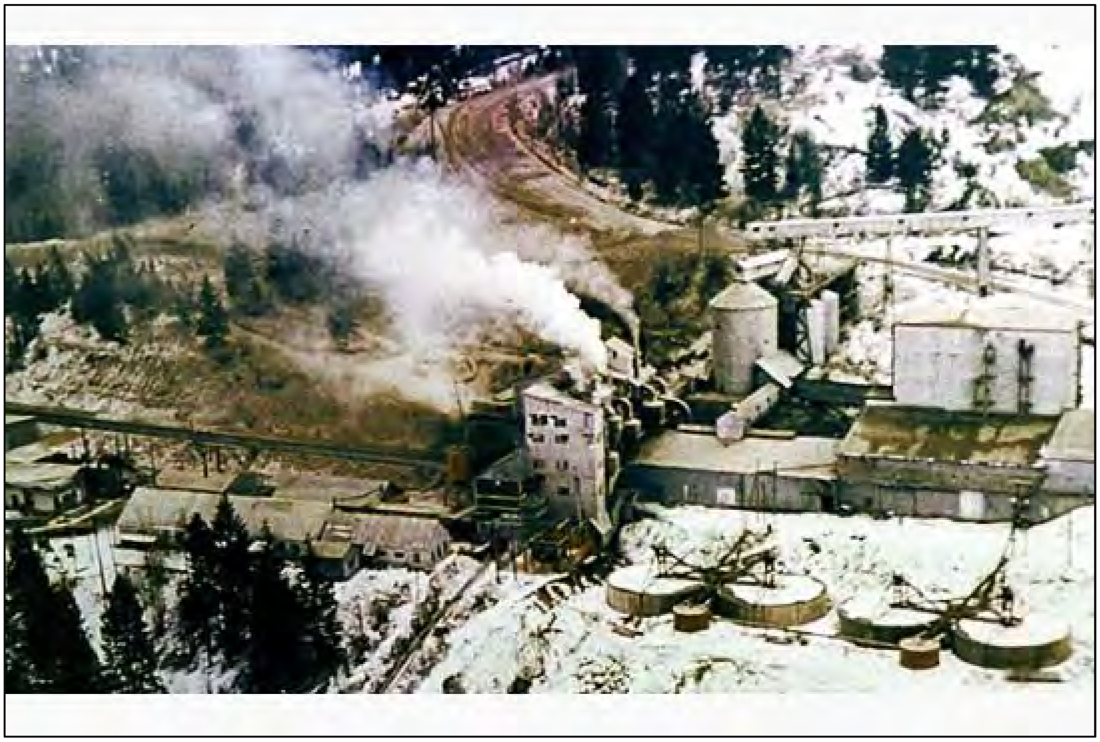
Mining - Related Site Features

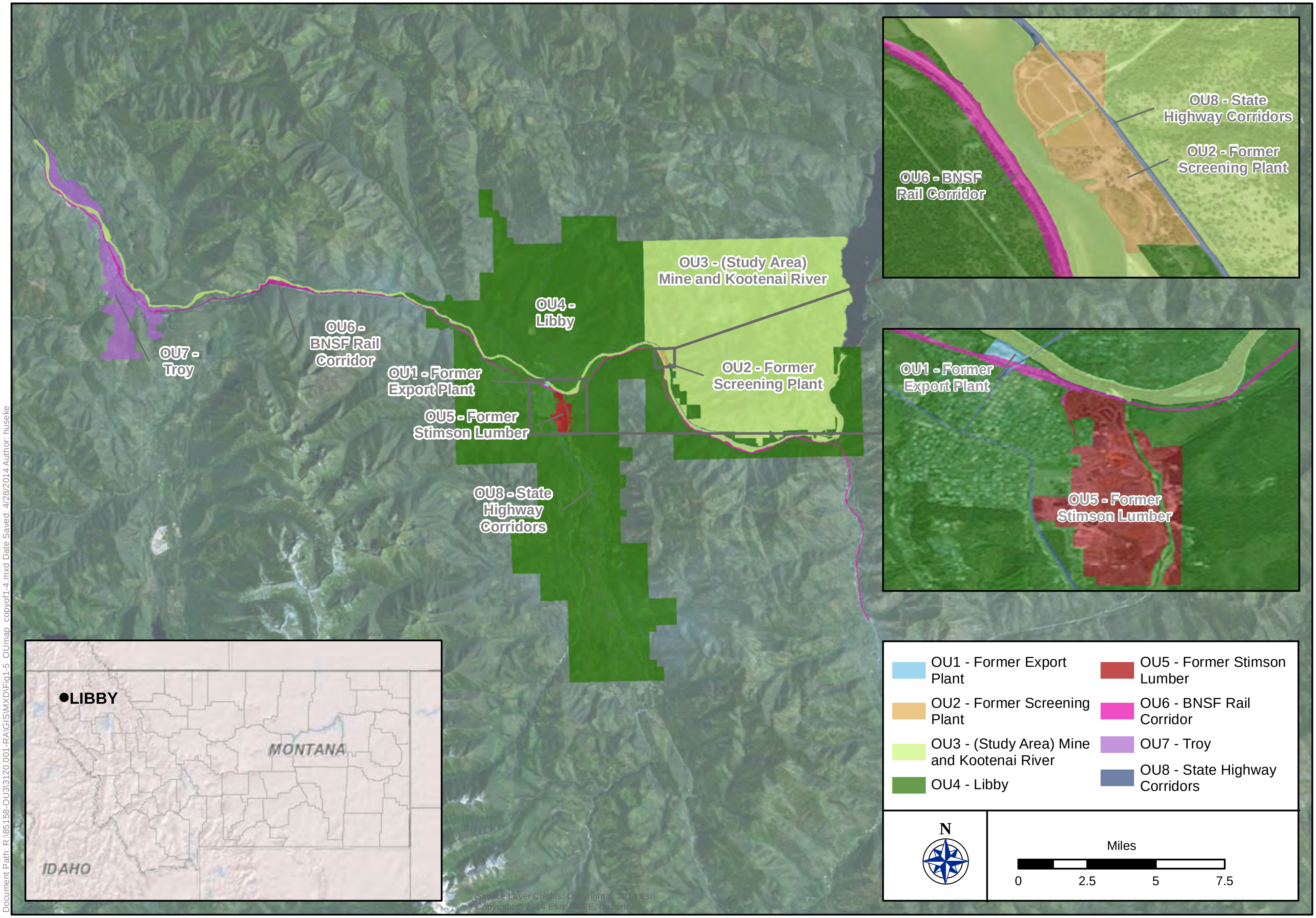
FIGURE 1-3

FIGURE 1-4

PHOTOGRAPH OF THE MILL AT THE VERMICULITE MINE IN LIBBY



SOURCE: LINCOLN COUNTY DISTRICT COURT / AP FILE PHOTO



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Libby Asbestos Superfund Site | Operable Units
Lincoln County, Montana

FIGURE 1-5

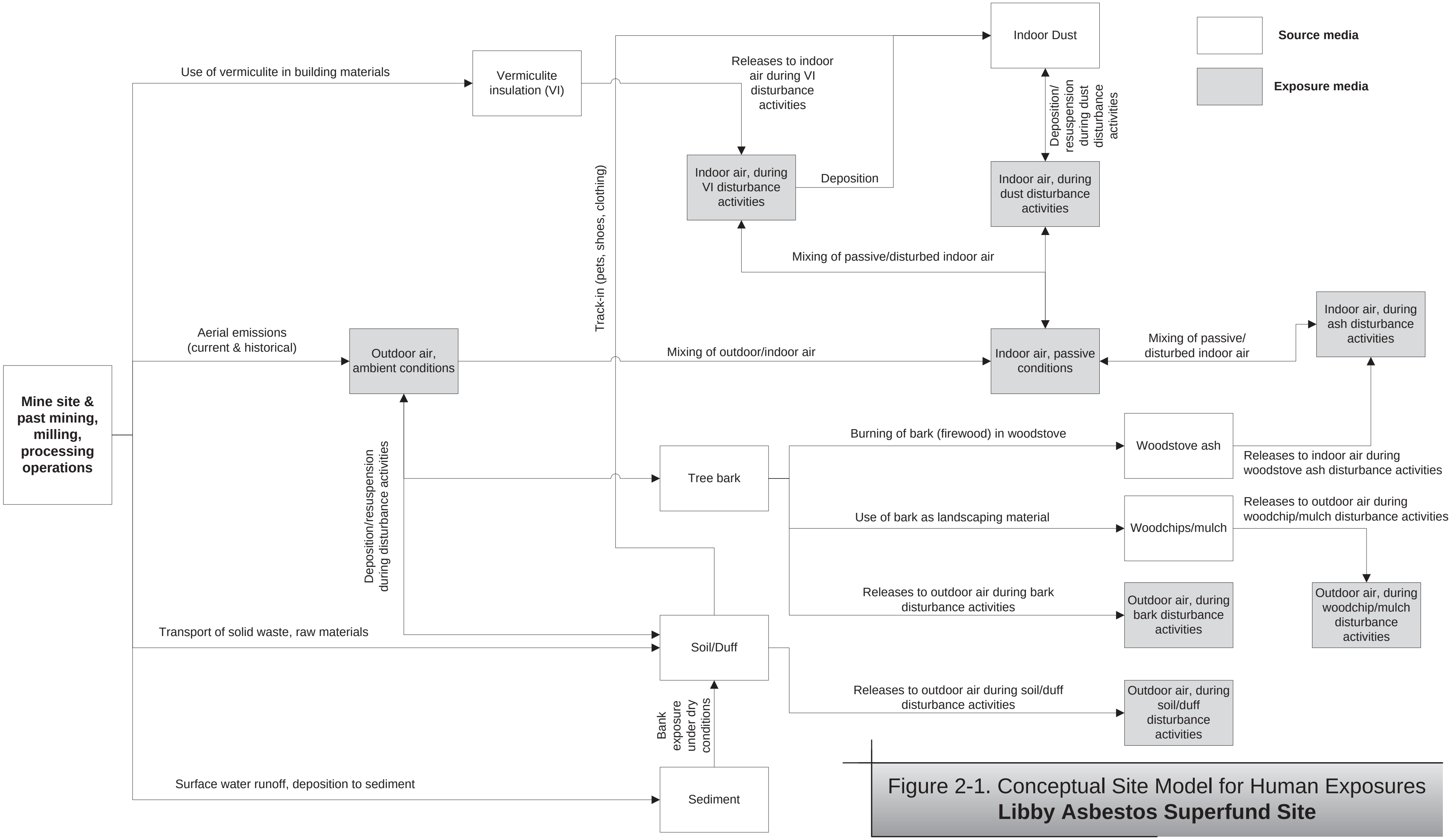
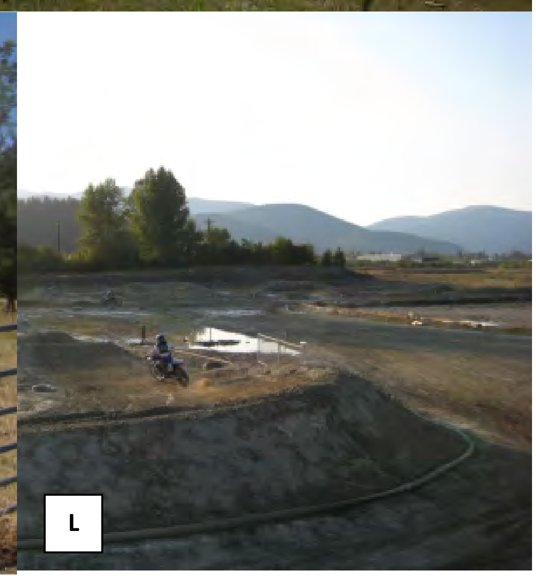


Figure 2-1. Conceptual Site Model for Human Exposures
Libby Asbestos Superfund Site

FIGURE 2-2. EXAMPLE PHOTOGRAPHS OF ABS ACTIVITIES

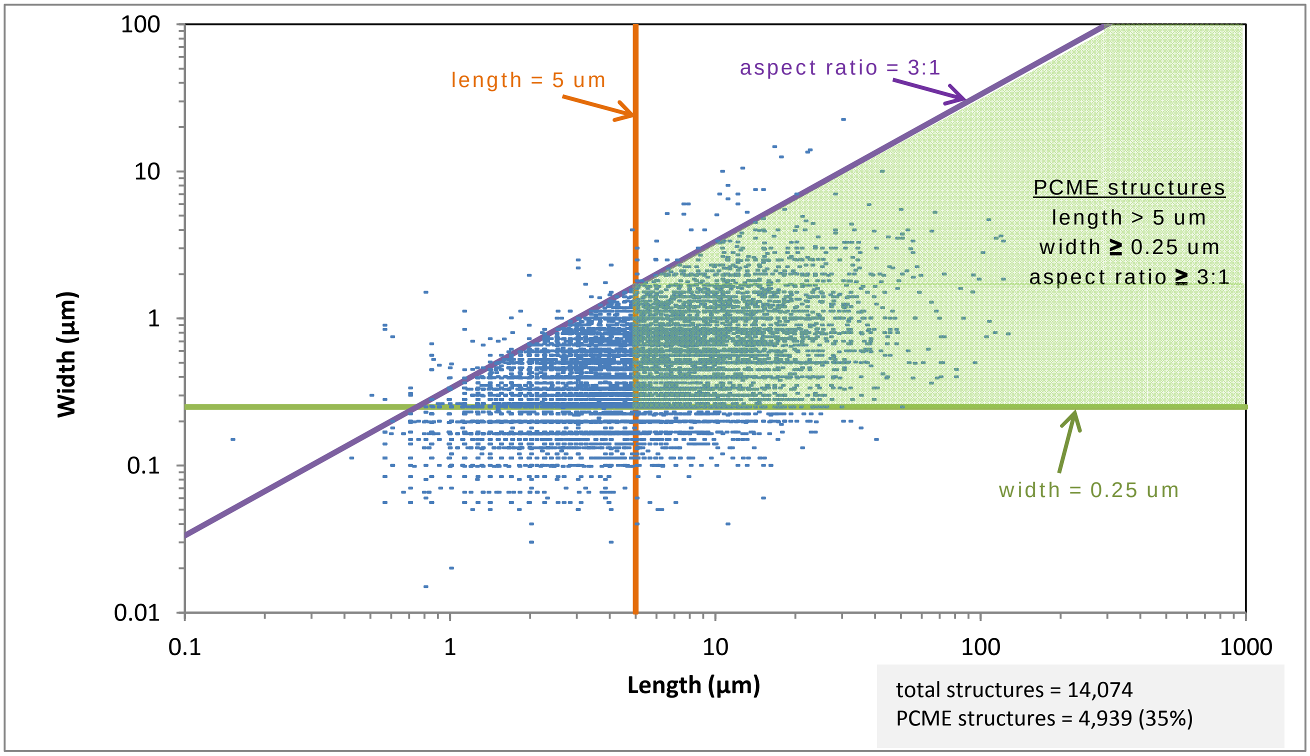
[A] Mowing lawn in a yard
[B] Biking along road in Libby
[C] Tricycling on unpaved driveway
[D] Raking leaves in a yard
[E] Sweeping floor inside a residence
[F] Digging in a yard

FIGURE 2-2. EXAMPLE PHOTOGRAPHS OF ABS ACTIVITIES (cont.)



[G] Playing frisbee
[H] Mowing lawn on a riding mower
[I] Playing on playground equipment
[J] Weed trimming
[K] Riding ATVs in unmaintained fields
[L] Riding motorcycles at the MotoX Park

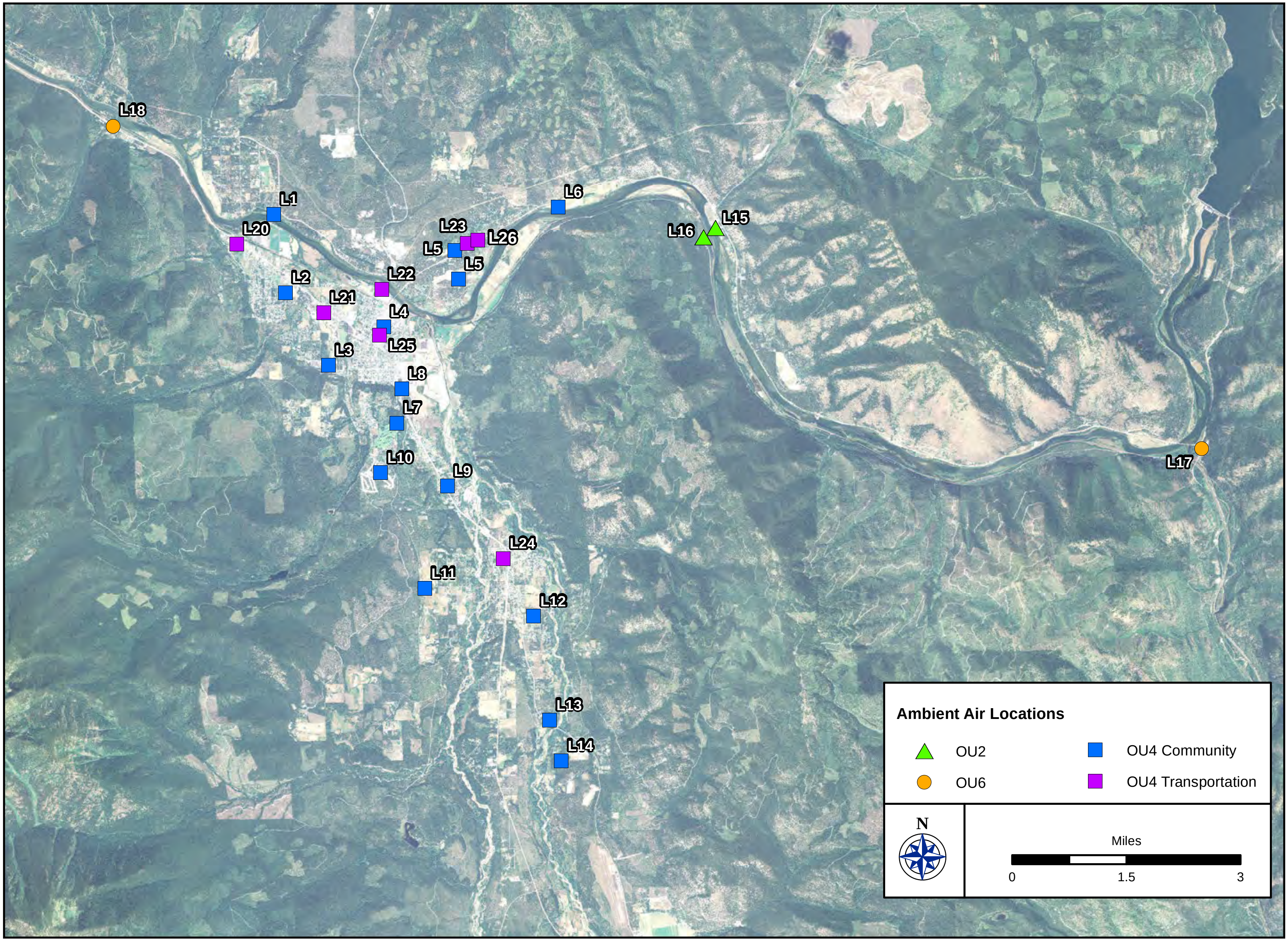
FIGURE 2-3. ILLUSTRATION OF PCME STRUCTURES



Notes:

µm = micrometer

PCME = phase-contrast microscopy - equivalent



Ambient Air Monitoring
Stations in Libby

FIGURE 5-1

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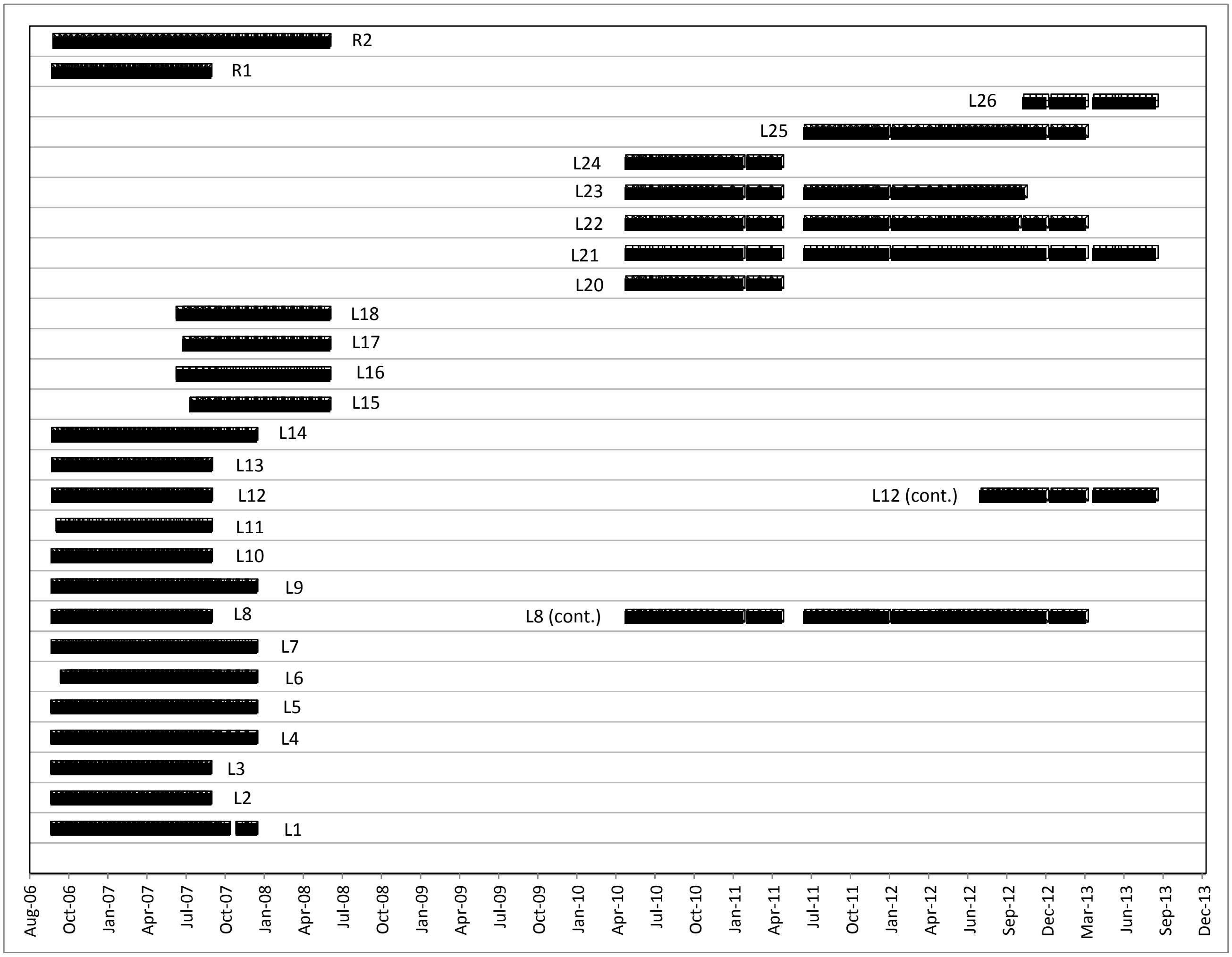
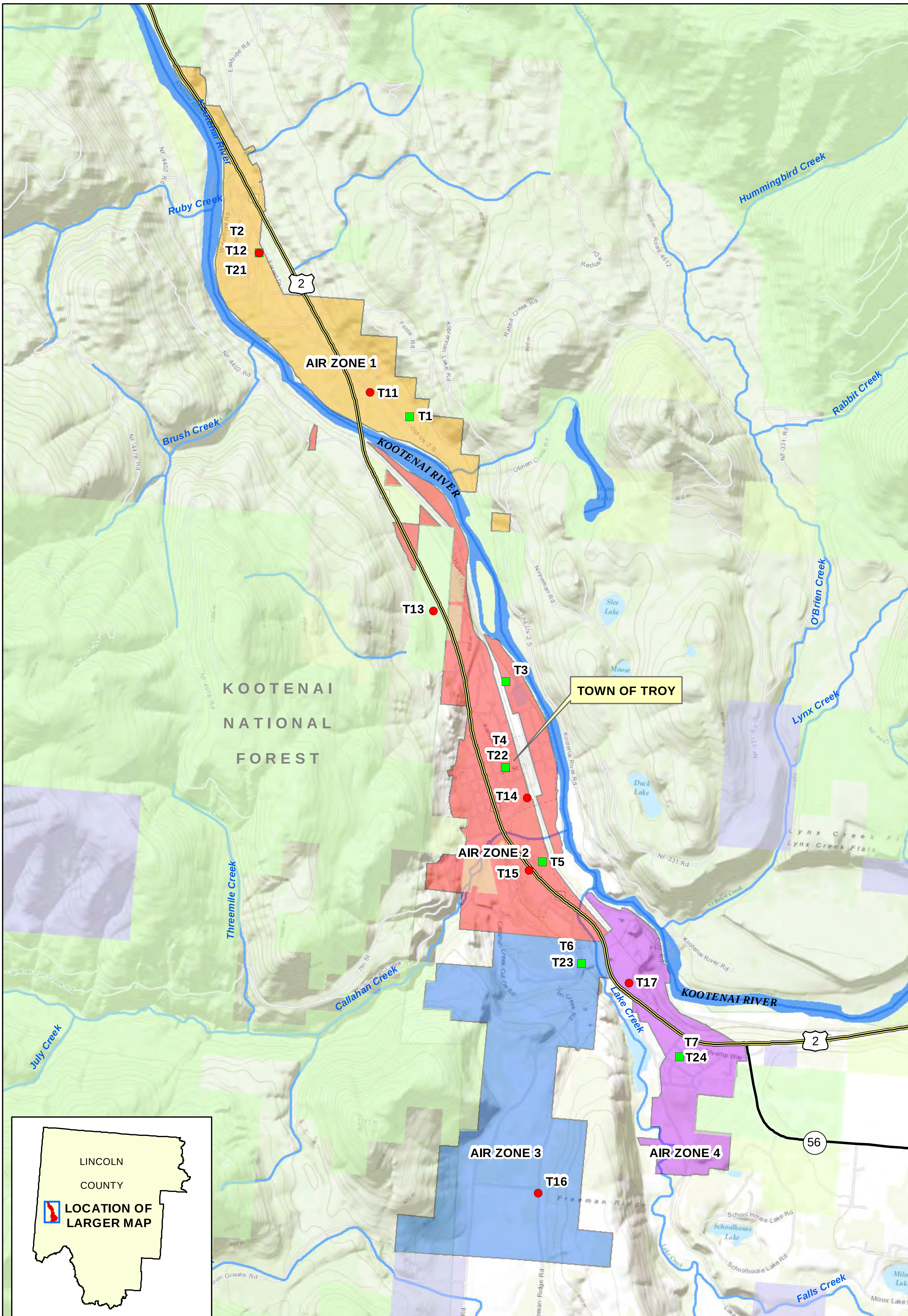
FIGURE 5-2
AMBIENT AIR SAMPLING DURATIONS FOR LIBBY, EUREKA, AND HELENA MONITORING STATIONS
Libby Asbestos Superfund Site, Libby, Montana



Monitor Location	Station ID	N Events	Station Description	Sampling Date Range
Libby (community)	**L1**	37	1915 Kootenai River Rd	Oct-2006 to Dec-2007
	L2	30	247 Indian Head Rd	Oct-2006 to Sep-2007
	L3	32	101 Ski Rd	Oct-2006 to Sep-2007
	L4	38	501 Mineral Ave	Oct-2006 to Dec-2007
	L5	38	1427 Highway 37 N	Oct-2006 to Dec-2007
	L6	36	3088 Highway 37 N	Oct-2006 to Dec-2007
	L7	36	378 Cabinet View Rd	Oct-2006 to Dec-2007
	L8	83	OU5, 60 Port Blvd	Oct-2006 to Aug-2007; May-2010 to Mar-2013
	L9	38	2261 Highway 2 S	Oct-2006 to Dec-2007
	L10	32	378 Cabinet View Rd	Oct-2006 to Sep-2007
	L11	30	Snowshoe Dr & Woodland Heights	Oct-2006 to Sep-2007
	L12	52	899 Farm to Market Rd	Oct-2006 to Aug-2007; Aug-2012 to Mar-2013
	L13	31	119 Evans Rd	Oct-2006 to Dec-2007
	L14	38	475 Fish Hatchery Rd	Oct-2006 to Dec-2007
	L15	16	OU2, 5002 Highway 37 N	Aug-2007 to Jun-2008
	L16	18	OU2, 4500 Highway 2 W	Jul-2007 to Jun-2008
	L17	17	OU6, Fisher River Bridge, Milepost 0.25	Aug-2007 to Jun-2008
	L18	18	OU6, 3501 Haul Rd	Jul-2007 to Jun-2008
Libby (transportation corridors)	**L20**	18	30414 US Highway 2	May-2010 to Apr-2011
	L21	60	32000 US Highway 2	May-2010 to Aug-2013
	L22	49	303 W Thomas St	May-2010 to Mar-2013
	L23	46	1675 MT Highway 37	May-2010 to Oct-2012
	L24	18	36304 US Highway 2	May-2010 to Apr-2011
	L25	33	Lincoln Blvd & Mineral Ave	Nov-2012 to Aug-2013
	L26	14	1799 MT Highway 37	May-2010 to Apr-2011
Eureka	**R1**	32	101 Iowa Flats Rd	Oct-2006 to Sep-2007
Helena	**R2**	39	1735 Missoula Ave	Oct-2006 to Jun-2008



Legend

2010 (Year 1) AMBIENT AIR SAMPLE STATION

2011 (Year 2) AMBIENT AIR SAMPLE STATION

AMBIENT AIR ZONES

ZONE 1

ZONE 2

ZONE 3

ZONE 4

0 1 Miles

N

TETRA TECH EM INC.

LIBBY ASBESTOS SUPERFUND SITE

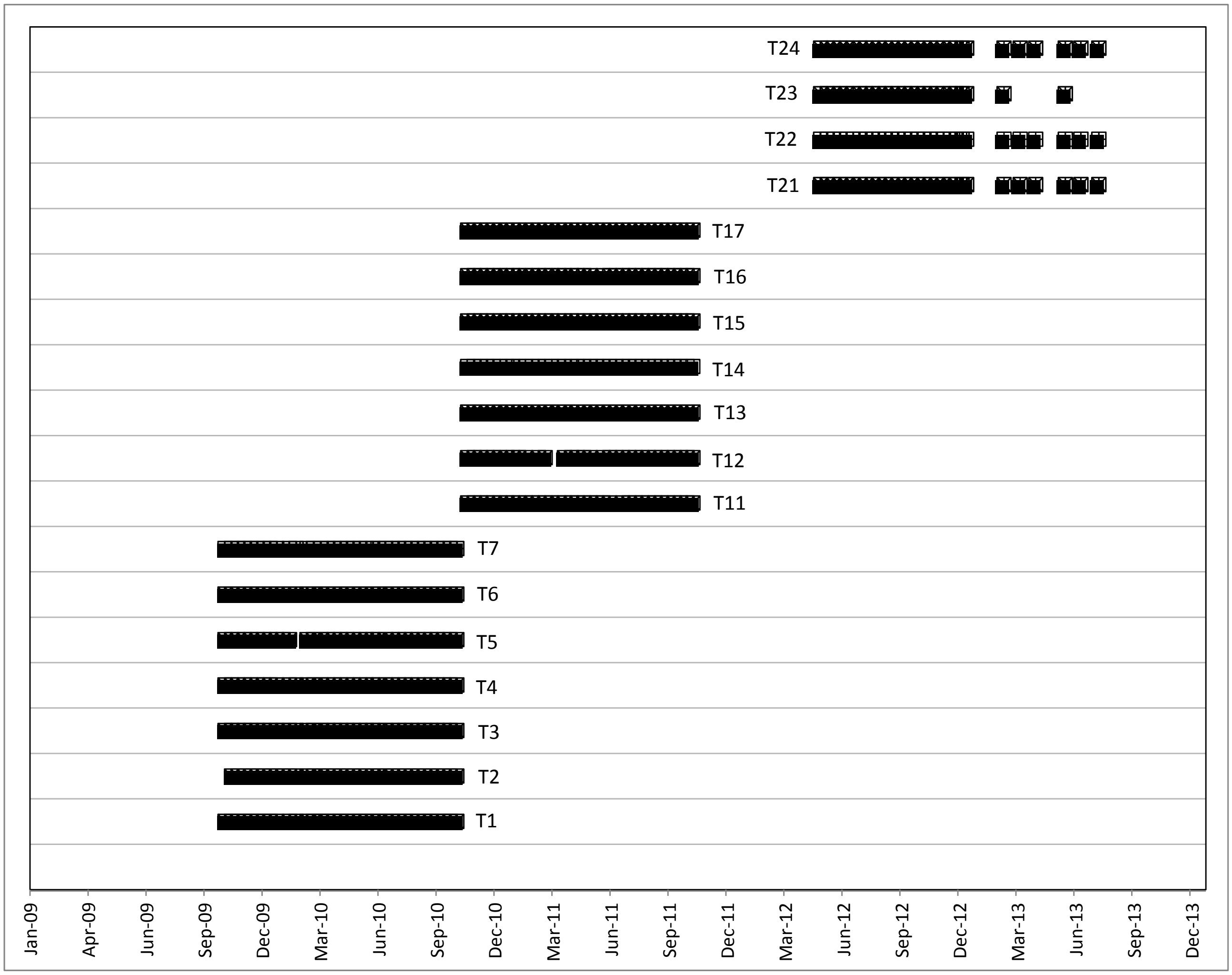
FIGURE 5-3
OPERABLE UNIT 7
OUTDOOR AMBIENT AIR
STATION LOCATIONS

GIS map by Ed Madej TTEMI-HE
FIG3-1_OU7RI_AMBIENT_AIR_122612.mxd

FIGURE 5-4

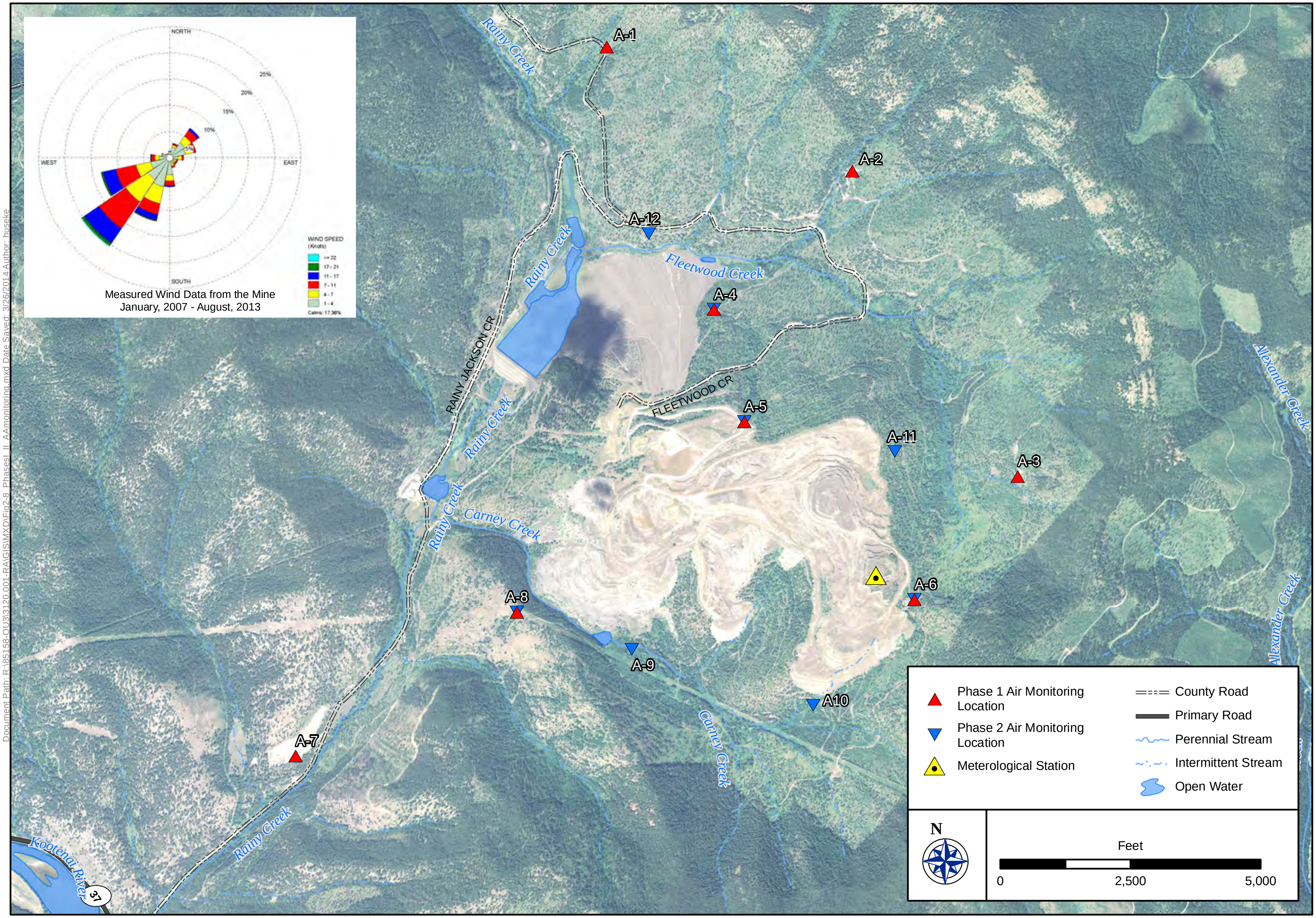
AMBIENT AIR SAMPLING DURATIONS FOR TROY MONITORING STATIONS

Libby Asbestos Superfund Site, Libby, Montana



Station ID	N Events	Station Description	Sampling Date Range
T1	35	Residential Property, North River Road	Oct-2009 to Oct-2010
T2	35	Fire Station in Kootenair Vista	Oct-2009 to Oct-2010
T3	36	Water Treatment Station, Roosevelt Park	Oct-2009 to Oct-2010
T4	35	MDEQ Troy Information Center	Oct-2009 to Oct-2010
T5	35	County Shops at Hwy 2-Sunset Road	Oct-2009 to Oct-2010
T6	36	Water Tower at Iron Creek Road	Oct-2009 to Oct-2010
T7	35	Residential Property, Wilderness Plateau	Oct-2009 to Oct-2010
T11	35	Community area NE of Kootenai River	Nov-2010 to Oct-2011
T12	32	Near northwest border of OU7 boundary	Nov-2010 to Oct-2011
T13	36	City of Troy, northern site	Nov-2010 to Oct-2011
T14	36	City of Troy, population center	Nov-2010 to Oct-2011
T15	36	City of Troy, southern site	Nov-2010 to Oct-2011
T16	35	Southwest OU7 boundary	Nov-2010 to Oct-2011
T17	36	Southeast OU7 boundary	Nov-2010 to Oct-2011
T21	30	North OU7 boundary	May-2012 to Dec-2012, Feb-2013 to Jul-2013*
T22	30	City of Troy, population center	May-2012 to Dec-2012, Feb-2013 to Jul-2013*
T23	26	City of Troy, southern site	May-2012 to Dec-2012, Feb-2013 to Jul-2013*
T24	30	Southeast OU7 boundary	May-2012 to Dec-2012, Feb-2013 to Jul-2013*

*Approximately one sample per month



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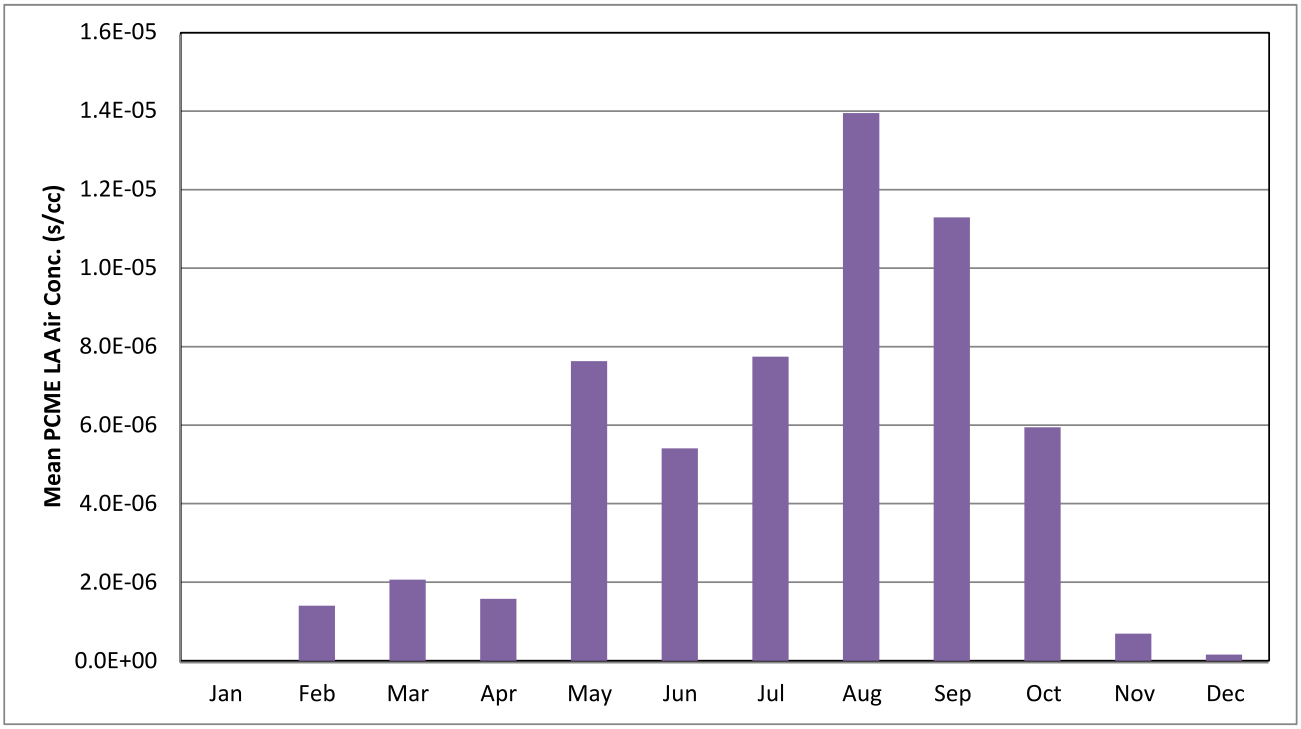
Ambient Air Monitoring Locations
Phases I and II

FIGURE 5-5

FIGURE 5-6
Temporal Evaluation of Mean Ambient Air Concentrations in Libby
Libby Asbestos Superfund Site, Libby, Montana



Based on monitoring stations in Libby (L1-L18)

s/cc - structures per cubic centimeter
PCME - phase contrast microscopy-equivalent
LA - Libby amphibole

FIGURE 6-1
Example of Exposure Area Spatial-Weighting Approach

Panel A: Exposure Area Soil Concentrations

Soil Sample #1:
Bin A

Soil Sample #2:
Bin B1

Soil Sample #3:
Bin C

Panel B: Estimated HQs* for Each Subarea

Bin A
Soil Concentration HQ = 0.1

Bin B1
Soil Concentration HQ = 2

Bin C
Soil Concentration HQ = 6

Panel C: Estimated Average HQ for the Entire Exposure Area

Exposure Area HQ =
(0.1 · 0.5) +
(2 · 0.25) +
(6 · 0.25)
= **2**

*Based on OU4 Yard Soil Disturbance ABS Residential RME HQs (see **Table 6-3a**)

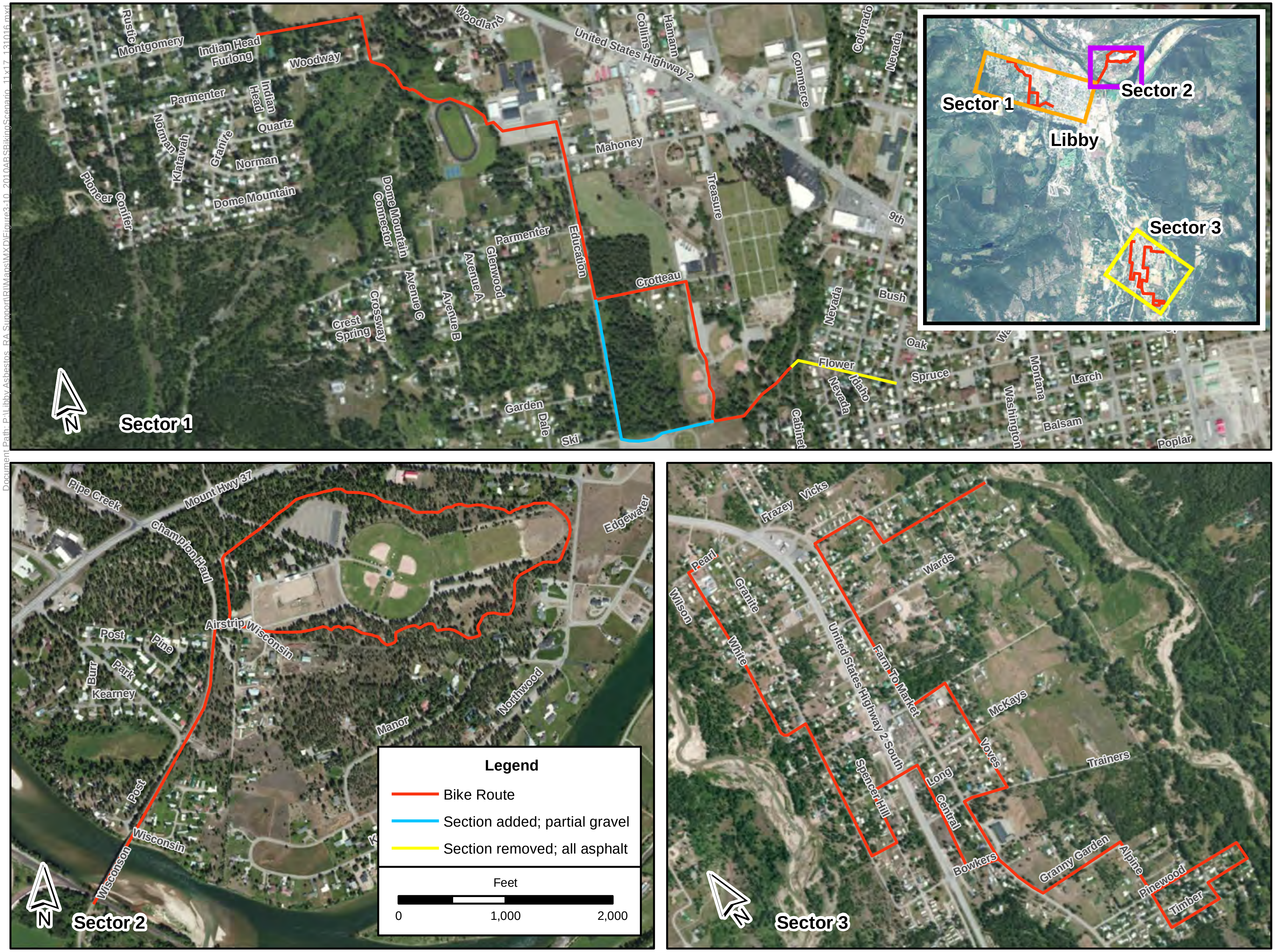
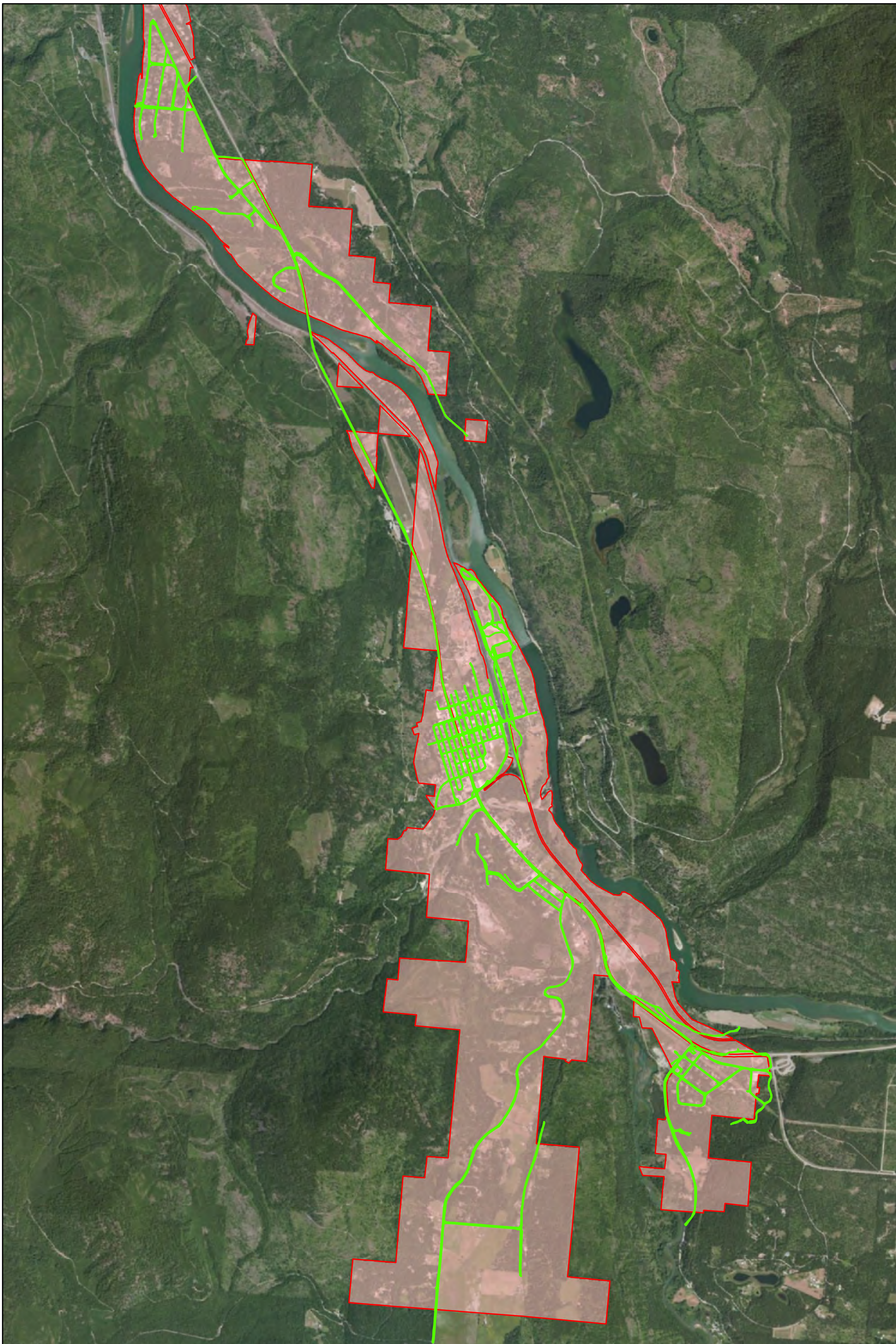


Figure 6-2
Libby Bicycle Routes



Aerial Imagery Source: Esri, DigitalGlobe, i-cubed,USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

LEGEND

ABS BIKE ROUTE - 2011

OPERABLE UNIT 7 AREA

N

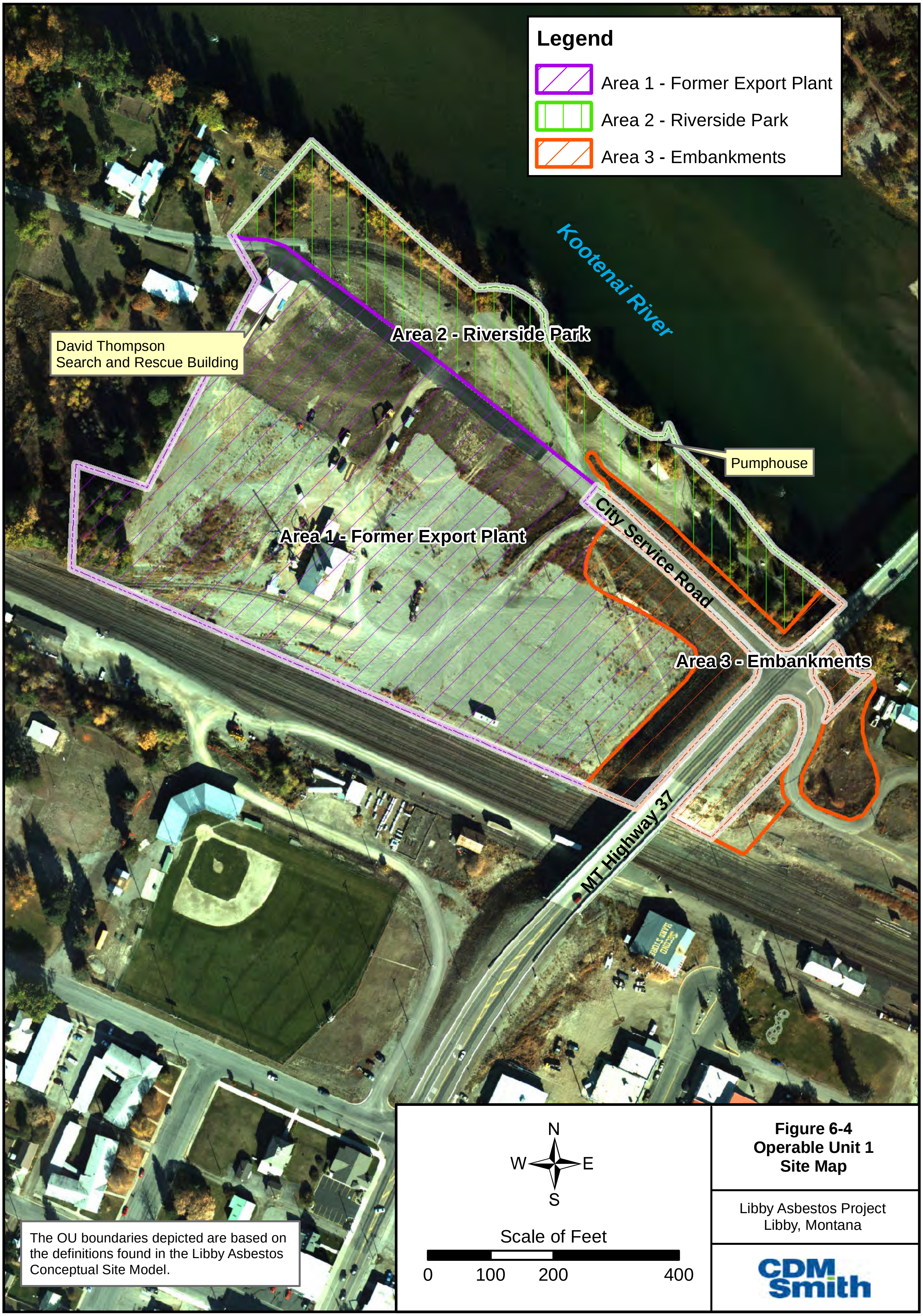
0 1 Miles

LIBBY ASBESTOS SUPERFUND SITE
LIBBY, MONTANA

FIGURE 6-3
2011 TROY ABS BIKE ROUTE COVERAGE

TETRA TECH EM INC.

Bike_Track_Base_Map_021414.mxd - DWH - TTEMI HELENA


Legend
Area 1 - Former Export Plant
Area 2 - Riverside Park
Area 3 - Embankments
Kootenai River
Area 2 - Riverside Park
David Thompson
Search and Rescue Building
Pumphouse
Area 1 - Former Export Plant
City Service Road
Area 3 - Embankments
MT Highway 37
The OU boundaries depicted are based on the definitions found in the Libby Asbestos Conceptual Site Model.
N
W
E
S
Scale of Feet
0
100
200
400
Figure 6-4
Operable Unit 1
Site Map
Libby Asbestos Project
Libby, Montana
CDM Smith